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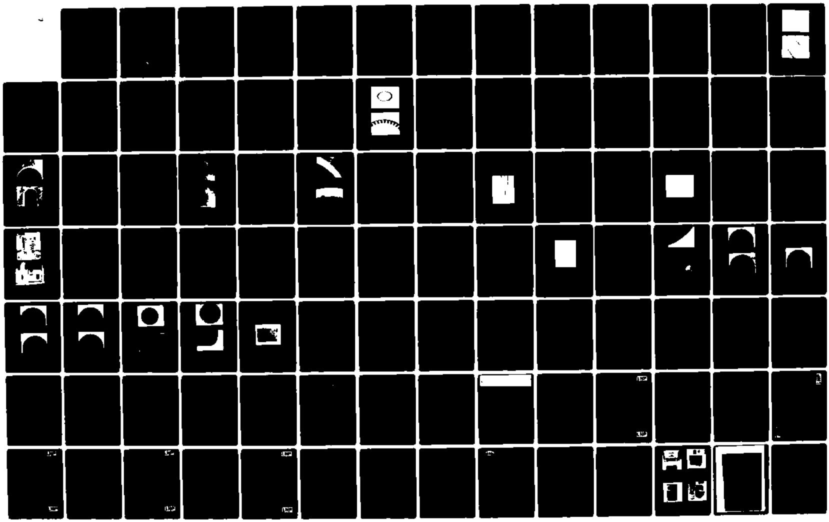

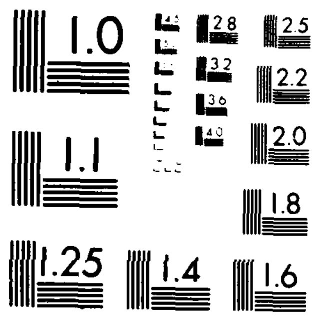

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FINAL REPORT

THE INSULATION OF COPPER WIRE BY THE ELECTROSTATIC COATING PROCESS

SUBMITTED TO:

U.S. ARMY MOBILITY EQUIPMENT
RESEARCH AND DEVELOPMENT COMMAND
ELECTRICAL POWER LAB, MERADCOM
FORT BELVOIR, VIRGINIA
22060

CONTRACT DAAK70-82-C-0061

JUNE 30, 1983

Magnetic Corporation of America

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A review of the fluidized bed electrostatic coating process and materials available for application to flat copper conductor has been made. Lengths of wire were rolled and electrostatically coated with two epoxy insulations. Electrical tests were made in air on coated samples at room and elevated temperatures. Compatibility tests in t e cooling/lubricating turbine oil at temperatures up to 220°C were also made. Recommendations for additional work are provided.

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FINAL REPORT

THE INSULATION OF COPPER WIRE BY THE ELECTROSTATIC COATING PROCESS

CONTRACT DAAK70-82-C-0061

Submitted to:

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Electrical Power Lab, MERADCOM
Fort Belvoir, Virginia 22060

Submitted by:

Magnetic Corporation of America
179 Bear Hill Road
Waltham, Massachusetts 02254

A-1

August 3, 1983

MAGNETIC CORPORATION OF AMERICA

FOREWORD

This is the final report on an investigation of the suitability of the fluidized bed electrostatic coating process for insulating generator stator conductor. The work was supported by the U.S. Army Mobility Equipment Research and Development Command (MERADCOM), Fort Belvoir, Virginia, under Contract DAAK70-82-C-0061. The program was monitored by Mr. Michael A. Mando of the Electrical Power Lab and the guidance and technical interfacing of Mr. Mando and Mr. C. Heise is gratefully appreciated.

The program manager and principal investigator at Magnetic Corporation of America was Dr. Martin G. H. Wells.

The work described in this report was conducted at MCA at its Waltham, Massachusetts facility with the following exceptions: Copper conductor was rolled by Durable Wire, Inc., Branford, Connecticut; the coating trials were conducted at Electrostatic Equipment Corporation, New Haven, Connecticut; and certain electrical tests were made at General Electric Company, Power Transformer Department, Pittsfield, Massachusetts and Doble Engineering Company, Watertown, Massachusetts.

At Magnetic Corporation of America, Messrs. E. J. Lucas, Dr. Z. J. J. Stekly, and J. F. Ferrante, were concerned with all phases of the work and analysis of the results. Dr. Bruce P. Strauss was involved with the above and with wire drawing and Dr. Frank Parks with partial discharge testing.

SUMMARY

Work conducted under this contract has demonstrated that conductor with an improved smooth bend radii blended into the conductor faces can be achieved and that the electrostatic coating process is capable of depositing a thickness of insulation on the conductor cross-section in proportion to the local field strength present.

Previous conductor, insulated with a film (solvent) process, has shown a tendency for depositing a thinner layer of insulation at the bend radii, where stress enhancement may be as high at 2.5 times that compared with the flat sides of the conductor. Thus the electrostatic coating process tends to correct for this condition and deposits extra insulation where needed. A number of powder coating materials have been investigated by electrostatic coating on conductor samples and these have been tested electrically for corona inception voltage (CIV), corona extinction voltage (CEV), breakdown voltage (E_B), and pinholes and for compatibility with the lubricant MIL-STD-L7808 turbine oil.

Additionally, all of the sample conductors have been cross-sectioned and evaluated under high magnification for the presence of voids, uniformity of insulation coating, and actual measurement of minimum and maximum insulation thickness.

The electrical tests show a broad range of breakdown voltages (from 200 to 2500 V/mil) and CIV voltage (from 150 to 1000 V/mil) both calculated on the basis of the maximum thickness of insulation measured. With one exception, all failures occurred at the bend radii of the conductor.

Analysis indicated the presence of voids as the primary cause of breakdown. A large variation in void size and population was noted among the samples, but in general, the conductor samples with the smallest and least number of voids achieved the better electrical testing results. The electrical breakdown results (conservatively based upon the maximum insulation thickness) were below those specified for each dielectric material by the supplier by a factor of 1.5 to 2.5 when field enhancement was not taken into account. However, when field is considered, the breakdown results are close to the material suppliers data.

Compatibility tests with the lubricant/cooling oil showed a range of results with none of the candidate materials fully satisfying the target requirement of 500 hours (with a 30% duty cycle at 220^{o}C). The dielectric properties of the lubricant/cooling oil were investigated and reported. Insulation resistance and power factor are very poor as compared with transformer grade mineral oil. The lubricant is close to 100% dissipation as a capacitor dielectric.

The work under the contract indicates that the electrostatic coating process, with improved controls, and with suitable powder coatings as identified in the report, coupled with improvements in producing smoother conductor bend radii, can be developed to satisfy the conductor requirements as defined in the contract statement of work.

The work performed under this contract clearly indicates that the potential exists for the development of a conductor insulation process that can virtually eliminate the need to provide a ground insulation of high electrical and mechanical integrity. The means to the realization of this potential rests in clearly defined and achievable development work to provide void and pinhole free conductor insulation via the electrostatic coating process.

THE INSULATION OF COPPER WIRE BY THE ELECTROSTATIC COATING PROCESS

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I. INTRODUCTION

A. Background

The goal of this program is to investigate the suitability of using the electrostatic coating process to meet MERADCOM's special requirement for insulated wire. Specifically, the program addresses the insulation of flat copper conductor for stator windings for a very high specific power output generator.[1]

In the development of the generator to date copper conductor insulated with "Pyre-M.L." polyimide enamel applied by the film (die coating) process has been used. Each of the 48 stator coils consists of 6 turns of this wire. A stator coil wound wit conductor electrostatically coated with epoxy during the program shown in Fig. 1.

B. Insulation Performance Criteria

The performance criteria for the insulation wire defined in the program statmenet of work is as follows:

1) Operate at 200-300 V/mil without breakdown and with minimum partial discharges.

2) Operate at 220^{o}C (428^{o}F) with a 30% duty cycle.

3) Be compatible with cooling oils, MIL-STD-L7808 or L-23699.

4) Be pinhole free.

5) Have good flexibility and abrasion and cut-through resistance.

6) Have a thermal and electrical lifetime of 500 hours.

C. Outline of Program Approach

The approach used by MCA in this program is outlined below:

1) The first task was to review the properties and establish candidate materials capable of meeting the insulation requirements which are suitable for application by the electrostatic powder coating process, particularly those with good thermal and chemical resistance.

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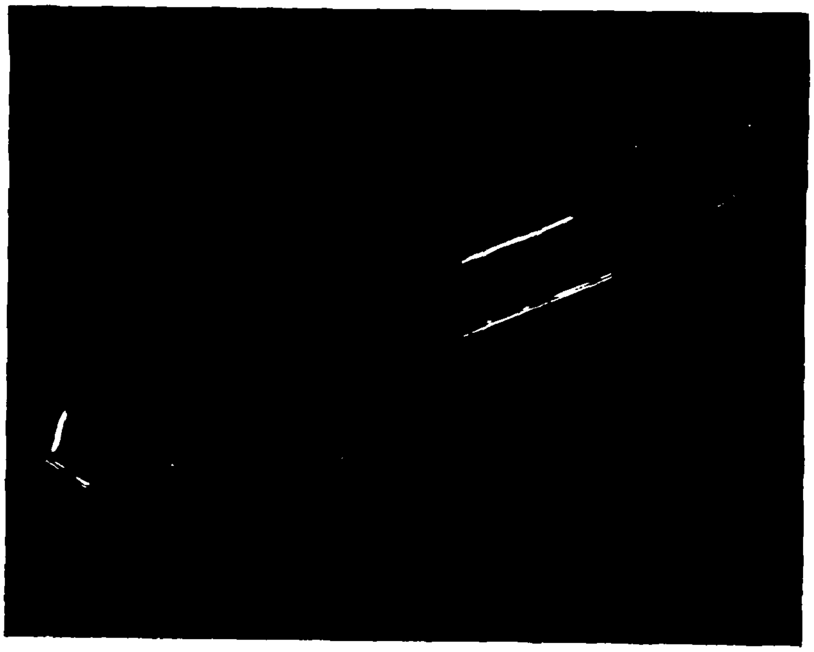

Figure 1 The photograph at the top shows a complete 6-turn stator coil. A closer view of the bends at the end is shown in the lower view.

2) A parallel task was to review and evaluate the various operating parameters of the electrostatic coating process to determine the suitability and/or limitations with respect to the available polymers.

3) Undertake a series of iterative coating runs on small samples using selected materials to establish suitability by conducting tests.

4) Upon completion of various test phases and after optimization of the operating control parameters, a sufficient quantity of insulated wire would be produced to fabricate full size stator coils.

In the course of the investigation, it was recognized early that the wire supplied by MERADCOM had a poor cross-section (that is, with sharp edges and the length was insufficient for both set-up and a coating run. It was, therefore, decided and authorized to manufacture a sufficient length of wire for these purposes.

5) The final task was to review the experimental results and identify shortcomings and problem areas and make recommendations for continuing work.

II. DESCRIPTION OF ELECTROSTATIC COATING PROCESS

Two methods have been used to apply polymer powders to wire by the electrostatic process: fluidized beds and gun spraying. However, gun spraying is difficult to control and may only be used for short duration runs. The fluidized bed method has now evolved into the only commercial process used for magnet wire insulation.[2-4]

The process has been under development for some 20 or more years. Early applications were mainly for corrosion resistance and decorative purposes and included fence wire, water pipe, window screening, and flexible hose. Work has been underway for about 15 years on development of the continuous fluidized bed powder coating process for applying

insulation to electrical conductors. Applications include telephone wire, small round magnet wire, and in recent years insulation of flat copper conductor for small and medium distribution transformers.[5-7].

The major functional components of a fluidized bed electrostatic coating line are given schematically in Fig. 2. These comprise a cleaning station, the fluidized bed coater, the curing oven and a quenching unit. Pay-off and take-up equipment completes the line, although ancillary equipment such as a wire splicer and quality control devices for electrical properties (pinholes) and dimensions are also usually provided. A drawing of a complete single wire line that was installed some years aso is shown in Fig. 3. The most recent installations are mostly more complex multi-wire lines. The main operating parameters that affect coating thickness and integrity and economy are:

- Surface Condition of Wire
- Applied Voltage
- Coater Baffle Positioning
- Oven Temperature

Details of these units are given later in this section.

The majority of the wire powder coating lines being installed utilize "B" stage epoxies and are of the horizontal type although the process can also be used in vertical systems.[8] All the process stations can handle several wires simultaneously. The number of wires that are run is decided by analysis of the investment required for handling equipment required for each strand as a function of the productivity required. The process is now cost effective for both round and rectangular wire larger than 20 AWG (0.032 inch diameter) when compared with conventional die coating or extrusion lines. Major manufacturers of telephone wire now insulate with the process and major producers of transformers, such as

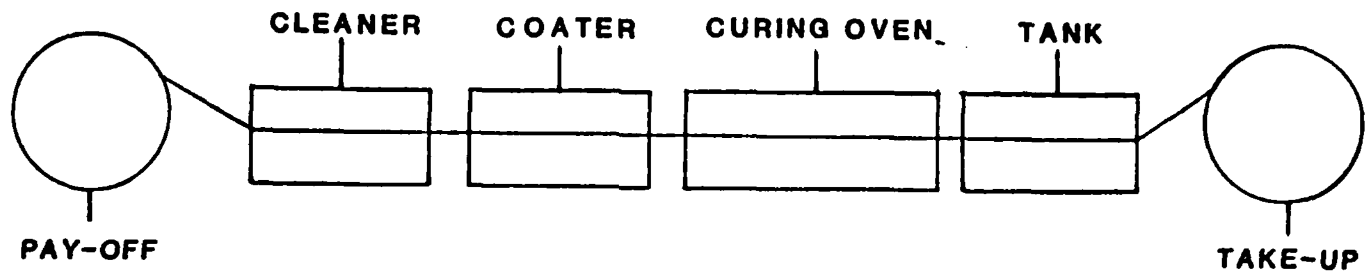

Figure 2 MAJOR ELEMENTS OF ELECTROSTATIC COATING LINE

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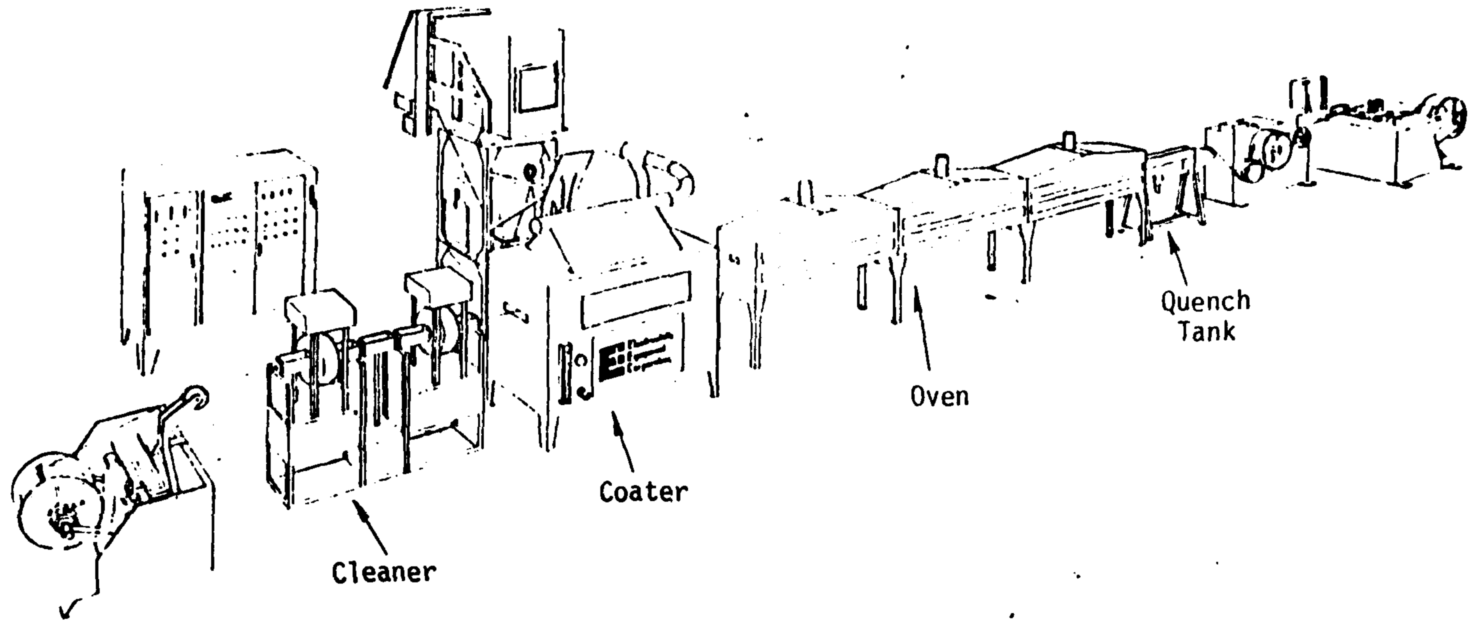

Figure 3 **SCHEMATIC VIEW OF ELECTROSTATIC WIRE COATING LINE**

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Westinghouse and General Electric, have been in commercial production and/or are presently installing new electrostatic coating lines for transformer wire using epoxies.

The use of dry powder has a number of advantages compared with the traditional film-coating process still used to insulate most magnet wire. In particular, the process eliminates pollutants, provides higher coating speeds especially on larger conductors, reduced energy costs, higher quality products, lower maintenance costs, lower reject rates, and the advantage of one pass coating.

During the past several years, there have been considerable improvements in the process equipment and also in the knowledge and control of the important operating parameters mentioned above. Together with process optimization there have been recent breakthroughs by powder polymer manufacturers that have led to improved dielectric strength, faster cure times (thus higher production speeds), and may be tailored for flexibility, solvent resistance, high temperature dielectric strength, etc. For example, the epoxies used to insulate transformer wire are supplied in the "B" stage condition, that is they are partially cured before application to the wire.

The list of polymers available includes polypropylene, nylon, urethane, polyester, and in recent years epoxies for higher temperature applications. Development is continuing on polymers for powder coating with further improvement in thermal and chemical resistance. Included in this category are the fluoroplastics such as ETFE (ethylene-tetrafluoro ethylene), FEP (fluorinated ethylene propylene), ECFTE (ethylene-chlorotrifluoro ethylene), and PFA (perfluoroalkoxy resin). Another material of interest with good elevated temperature properties is polyphenylene sulfide. A more detailed discussion of polymers is given in Section III.

Batch Coating - In addition to continuous wire coating, the fluidized bed process is used extensively in batch or individual part in-line coating processes. The automotive generator stator shown in Fig. 4 was coated with epoxy by this method. Selected coverage may be obtained by brushing off powder from those regions where no coating is desired before curing the part. The inside and outside surfaces have had the powder removed in this case.

This method was used in the program to apply polymers to small samples for experimental purposes.

New Developments - There are two areas of development activity that are of particular interest to conductor coating for MERADCOM's requirements. Consideration is now being given to in-line thermal treatment of the wire for annealing and cleaning. Die coating lines presently employ a preheat oven to burn off any remaining lubricant or other organic matter and high temperature fluidized beds are being investigated for this purpose. These beds have good heat transfer characteristics and could also be used to anneal the cold-worked copper conductor. In addition, some of the newer high temperature chemically resistant polymers require preheat of the wire before the powder application.

In many respects, it would be very desirable to cure the polymer by heating from the inside out. The material at the conductor interface would then melt first and curing would take place progressively from the inside to the outside surface. During curing, air in the powder interstices would then be driven out preventing the entrapment of small bubbles. There is, therefore, considerable impetus and development work continuing on induction heating systems that would accomplish this goal. It is likely that in the future lines will more frequently have induction heating or induction/infrared curing systems. Such system development

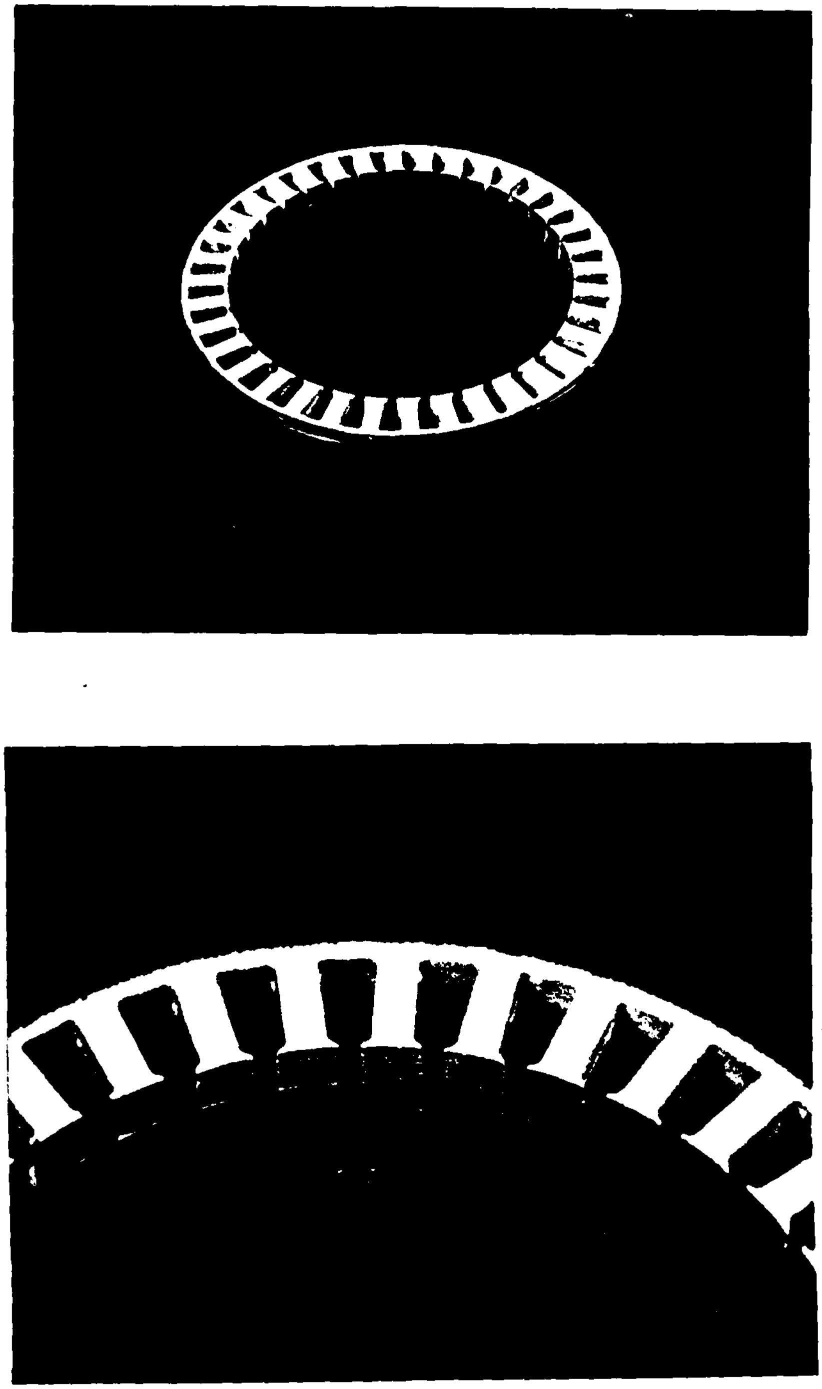

Figure 4 Photographs showing an automotive generator stator (5" diameter electrostatically coated with an epoxy by the fluidized bed process. Note the good edge coverage.

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will go hand in hand with new polymer development such as the higher thermal resistance types that require higher curing temperatures.

III. MATERIALS AND COATING TRIALS

A. Review of Coating Materials Available

At the outset of the program, a review was made of the polymers available for continuously coating wire by the electrostatic fluidized bed process. Powders available include epoxies, several fluoroplastics such as ETFE, FEP, and ECTFE, nylon, polyesters, polyethylenes, polypropylenes, and urethanes. Some characteristics of these classes of polymers are given in Table I and notes on each class of polymers is given below:

1) Acrylic - Acrylics encompass a large family of thermoplastic and thermoset resins. Acrylics are characterized by crystal clarity and excellent weatherability and a useful combination of stiffness,density and moderate toughness. They are good electrical insulators, but do not have particularly good thermal resistance. Acrylics may be applied by the electrostatic process but are not used as wire coatings. Because of their lower flexibility, they are applied to form substrates.

2) Epoxy - Epoxy resin is a family of materials that can be transformed into thermostat polymers by reaction with curing agents or hardeners. They offer a combination of properties such as good electrical insulation and mechanical properties, chemical and thermal resistance that makes them suitable for electrical insulation purposes. There has been a considerable development effort by a number of manufacturers on epoxy powder formulations. Epoxy powders may be quite complex[9] and at least contain the resin and a hardener and may contain one or more of the components, plasticizer, filler, pigment, and surfactant. However, the powders that are used for electrostatic applications mostly consist

TABLE I

INSULATION MATERIALS CONSIDERED

		Temperature Class	
1.	Acrylic	105°C	Not applied to wire.
2.	Epoxy	155°C	Highest temperature class polymer now applied by ECP* to wire.
3.	Fluoroplastics	220°C	Powders available. Coating methods and powder development underway.
4.	Nylon	105°C	Good for low temperature applications.
5.	Polyester	155°C	Thermoset polymers with better temperature resistance are used in solution coated enamelling - cannot be powder coated. Thermoplastics can be applied by ECP.
6.	Polyimide	220°C	Excellent high temperature properties, but cannot be powder coated.
7.	Polyphenylene Sulfide	220°C	Can be applied by ECP, but cannot presently be commercially applied to wire by the continuous process because of the long cure times required.
8.	Polypropylene	105°C	Low temperature - used for decorative purposes, i.e. fence wire, etc. and house wiring.
9.	Polyurethane	105°C	Has been used successfully. More expensive than nylon.

*Electrostatic Coating Process

principally of resin and hardener. Data sheets for the epoxies used in the program are given in Appendix B.

3) Fluoroplastics - Fluoroplastics are a family of polymers with the general paraffin structure that have some or all of the hydrogen replaced by fluorine. Fluoroplastics have very high chemical resistance and wide useful operating temperatures (up to 260°C). In addition, they have very good electrical insulating properties. Most fluoroplastics have a low coefficient of friction ar⁻ are thus used where non-adhesive properties are required and in a variety of industrial seals, rings, and bearings. Many of these materials may creep under load. That is, they have poor cold-flow properties, but have excellent high temperature endurance.

Fluoroplastics are among the high temperature polymers presently undergoing development. Several polymers are available in powder form for application by the electrostatic process, but none is presently being applied commercially to wire. Among materials available are ETFE (ethylene-tetrafluoroethylene copolymer), PFA (perfluoroalkoxy resin), ECTFE (ethylene-chlorotrifluoroethylene), and FEP (fluorinated ethylene propylene). Data sheets and other information on several of these polymers is given in Appendix C.

4) Nylon - Nylon is the common name for a family of closely related melt-processable thermoplastics whose polymer chains are characterized by repeating amide groups. They make up the largest and oldest class of engineering thermoplastics finding use in a wide variety of applications. Nylons have good chemical resistance and thermal resistance up to 105°C and thus are not capable of withstanding the temperatures found in this application. Nylon can be applied continuously to wire by the electrostatic coating process and is used extensively for insulation of telephone wire.

5) Polyester - Polyesters or copolymers comprise a number of different materials including both thermosets and thermoplastics. Polyesters are being commercially applied to wire by the electrostatic coating process for applications such as fence wire and small round magnet wire (see reference 10).

6) Polyimide - Polyimides are perhaps the most heat resisting polymers known and are available as both thermoset and thermoplastic types. Some thermoplastic types appear to behave as thermosets, that is, they exhibit no distinct softening point below their thermal degradation temperature. "Pyre-M.L.", the enamel presently used for the generator stator wire insulation, is a polyimide. These enamels are solutions of polyamic acids formed by the reaction of aromatic diamines with aromatic dianhydrides. While the polyimides exhibit exceptional thermal and chemical resistance unfortunately they cannot be applied by the powder electrostatic coating process because their melt temperatures are above the temperature at which permanent degradation of the polymer occurs, i.e. charring, etc.

7) Polyphenylene Sulfide - This material is a crystalline aromatic polymer in which recurring para-substituted benzene rings and sulfur atoms form its symmetrical rigid backbone. The sulfur-benzene ring bond is thermally stable and accounts for the high melting point and temperature and chemical resistance. PPS is available as a powder for electrostatic coating. But as the data sheets show (see Appendix C), PPS requires a long cure time (45-60 minutes) at a high temperature and is not, therefore, presently continuously applicable to wire. In addition the part should be preheated. These requirements really dictate an inert atmosphere oven to prevent oxidation of the copper surface. Because of the very promising

properties of this polymer, it is recommended that development work be undertaken to improve flexibility and decrease the cure time by other means such as radiation curing.

8) Polypropylene - Polypropylene is one of the fastest growing thermoplastics available. The range of properties exhibited by polypropylene is due to the ordered arrangement of monomer and comonomer units in the long chain configuration making up the molecular structure of the polymer. Since it is non-polar, polypropylene has good dielectric and insulating properties and is essentially inert to most chemicals at ambient conditions. Polypropylenes may be applied by the electrostatic coating process and are used extensively for decorative corrosion resistance applications such as fence wire. It may also be used to insulate household wiring. Polypropylenes are not suitable in the present application because of their temperature limitations.

9) Polyurethane - Polyurethanes are addition polymers obtained from the chemical reaction of an isocyanate and a polyol. They may be formulated to have a wide range of properties from soft thermoplastic elastomers to hard thermoset rigid foams. Polyurethanes may be applied by electrostatic coating and have been used for electrical insulation purposes, but in a number of applications have been replaced by less expensive nylon. Like polypropylene, polyurethanes are not suitable for elevated temperature service.

B. Wire Production

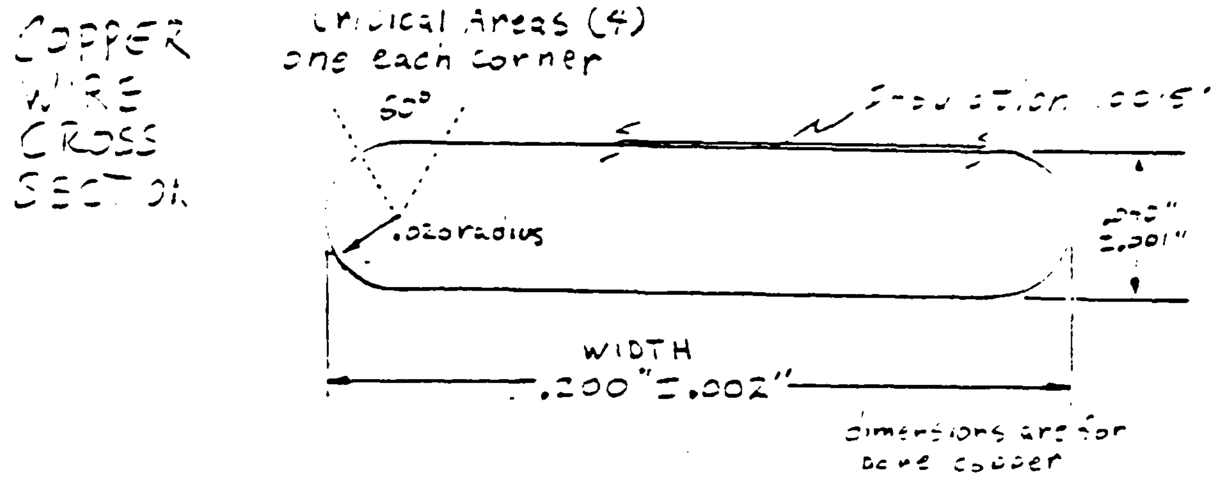
During review of the materials available for electrostatic coating, it was learned that several hundred feet of wire is necessary to set-up a line for coating. In addition, from experience at MCA, it was recognized that a good wire profile is vitally important in obtaining a good uniform insulation. That is, no sharp asperities can be present. It was therefore decided to produce a sufficient length for trials.

About 8000 feet of conductor was rolled with the dimensions shown in Fig. 5. Cross-section views of the ends of this conductor are shown in Fig. 6. The blend of the end radii into the side portions is quite good. A good blend with no small radius regions is essential in obtaining good uniform insulation. Sharp asperities may result in thinner coatings at those regions because of the surface tension of liquid or molten polymers. Such regions are likely to be thinner with coatings applied by the solution film (die coating) process than by the electrostatic coating method for two reasons: (1) The electrostatic attraction is higher at sharp radius projections and thus powder coating thickness may be greater and (2) the coatings have higher viscosity during cure because no solvent has to be removed. This thinning of the coating at a sharp projection was noted in the report on Contract DAAK70-79-C-0131[11] with "Pyre-M.L." coating on the MERADCOM stator wire.

C. Epoxy Wire Coating Trials

From the evaluation of materials it became apparent that epoxies are the best available class of powders for continuous application to wire. Two commercially available epoxies, 3M XR-5256* and Hysol DK31-0711* were selected for coating trials. (*Data sheets for these epoxies are given in Appendix B).

Lengths of copper conductor were then insulated with these two polymers on the pilot production line at Electrostatic Equipment Corporation, New Haven, Connecticut 06511. Following set up 833 feet of conductor insulated with 3M XR-5256 and 3462 feet insulated with Hysol DK31-0711 were retained for testing.



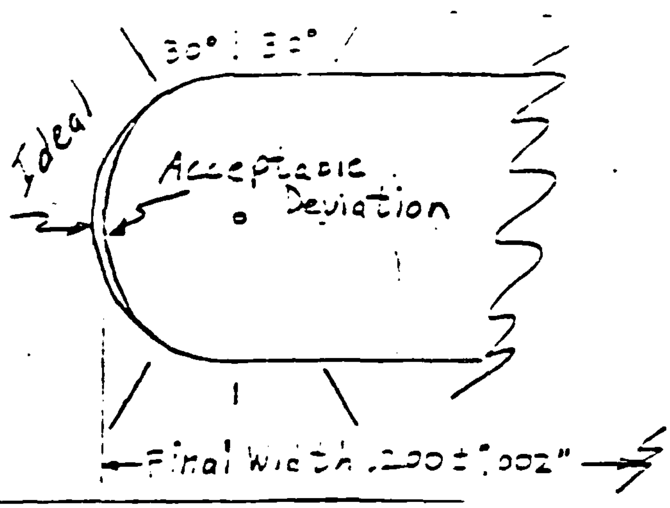
MATERIAL: Copper, purity and hardness to yield minimum conductivity of 100% IACS (.017241)

Rondal Lubricants Co
MIL - 7808 lubricant

SURFACE FINISH: 32 microns or better on copper. MIL - L23699B

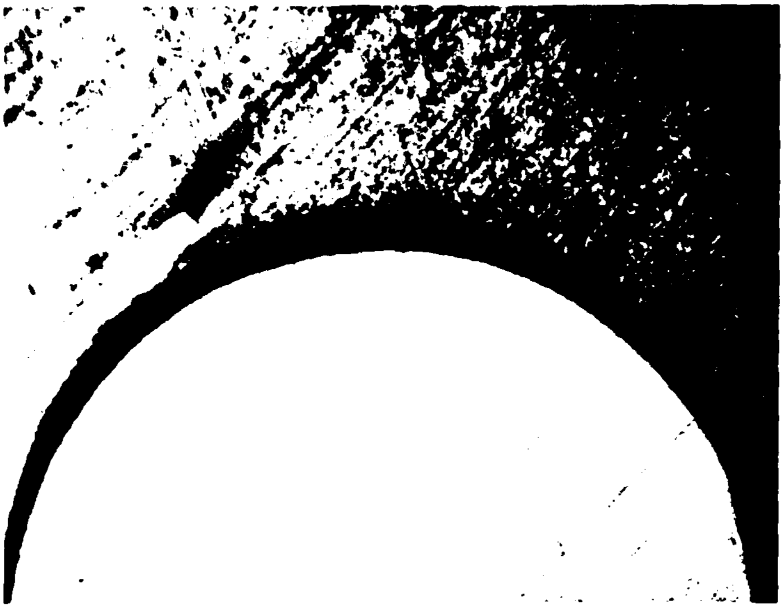
INSULATION: Heavy ML (220°C. Polyimide Varnish) or equal.
.0015" nominal thickness.
+.001", -.0005" Insulation shall not be less than .001" at any point.
ML quality per Fed. Spec. J-W-1177/15A

CRITICAL AREAS: The transition between the flat and full round must be smooth (32 microns) and properly shaped .020" radius ±.001". The radius between these areas may be larger provided the change is gradual and specified width is maintained. See example below.



TESTING: Acceptance will be determined by micrographic cross-sections at 50 - 200X magnification.

Figure 5 Generator Wire Specification



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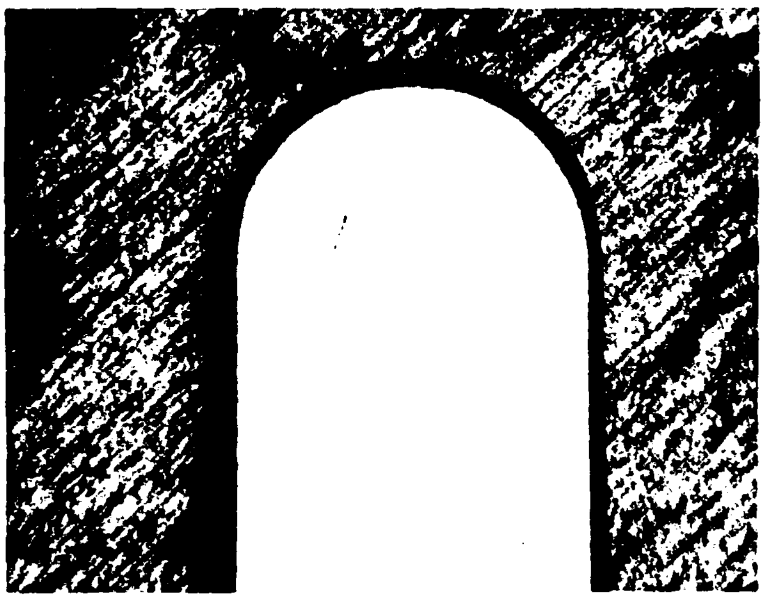

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Figure 6 Profile of rolled wire cross-section. Note the good blending of the radius into the flat sides

D. Batch Coating Trials

In view of the results obtained with the epoxy insulation, particularly the oil compatibility problems, it was decided to electrostatically coat round wires with some new polymers. Three materials were applied in an electrostatic fluidized bed batch unit:

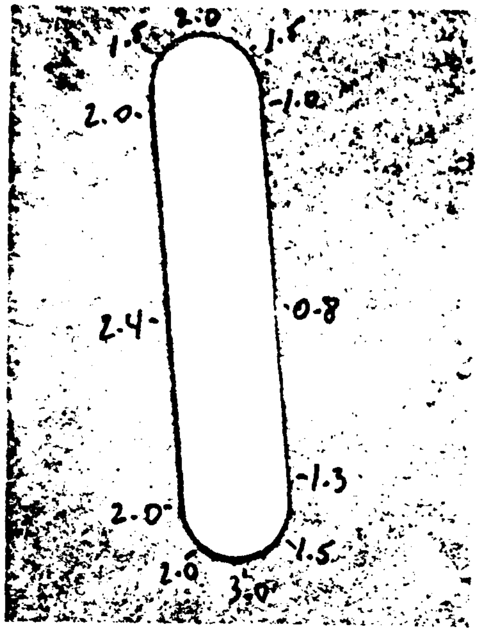
Epoxy	Polymer Corp. 1317-59-1
ETFE	LNP Corporation
PPS	LNP Corporation

IV. TEST RESULTS AND DISCUSSION

A. Evaluation of Epoxy Coatings

Dimensions: Cross- sections of the coated wire are given in Fig. 7 for 3M XR-5256 and in Fig. 8 for Hysol DK31-0711. The figures show that in both cases "dog-boning" occurred. That is, the insulation thickness is greater at the edges than along the flat faces. In some respects this condition is advantageous but in general a coating of uniform thickness is preferrable.

The 3M coated wire was cut into two sections and the Hysol product was divided into eleven lengths. The dimensions of the insulated conductor were then measured along these sections. The results are given in Table II (together with our dielectric breakdown data which will be described in the next section of this report). The dimension measurements showed that a variation of ±0.001 inch may be expected in a length of coated wire. This seems to be an inherent characteristic of the process particularly at the slower line speeds that were necessary on the experimental line used. Fig. 9 shows bubbles that are likely to form at slower line speeds. Faster full production lines produce more uniform coating thicknesses.



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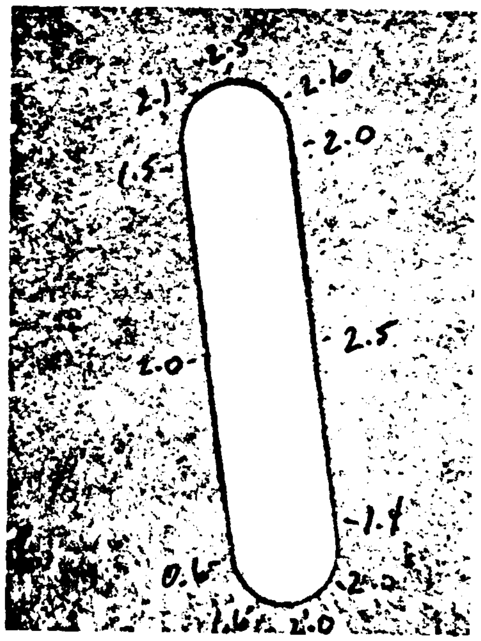

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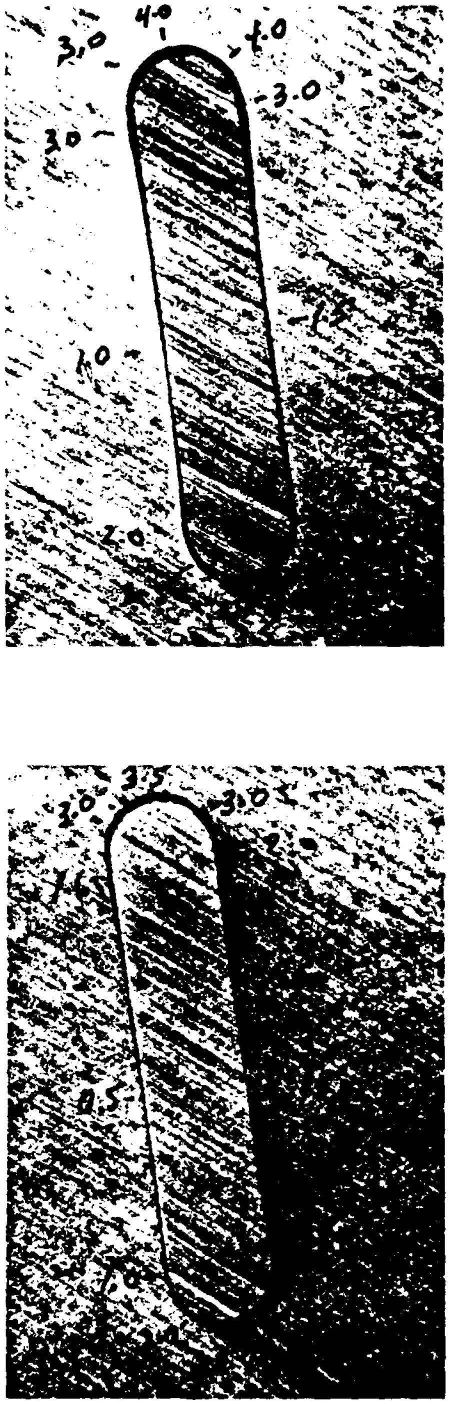
Figure 7 Cross-sections of wire electrostatically coated with 3M XR-5256 epoxy. The dimensions of coating thickness are given in mils



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15X

Figure 8 Cross-sections of wire electrostatically coated with Hysol DK31-0711 epoxy. The dimensions of coating thickness are given in mils

TABLE II

DIMENSIONS AND BREAKDOWN VOLTAGE OF COATED CONDUCTOR

	Coating Applied	Coated Dimensions* inches	dc Voltage Breakdown
1	3M XR-5256	0.044x0.203	500 - 1000
2	3M XR-5256	0.045x0.204	1200
3	Hysol DK31-0711	0.046x0.205	500 - 600
4	Hysol DK31-0711	0.046x0.206	2400 - 4200
5	Hysol DK31-0711	0.045x0.205	700 - 1100
6	Hysol DK31-0711	0.045x0.205	500 - 600
7	Hysol DK31-0711	0.043x0.203	500 - 575
8	Hysol DK31-0711	0.043x0.203	400
9	Hysol DK31-0711	0.046x0.204	700 - 1000
10	Hysol DK31-0711	0.044x0.204	500 - 550
11	Hysol DK31-0711	0.043x0.203	600
12	Hysol DK31-0711	0.043x0.202	500
13	Hysol DK31-0711	0.043x0.202	575

*Bare Conductor: 0.040"x0.200"

Copper

400X

Copper

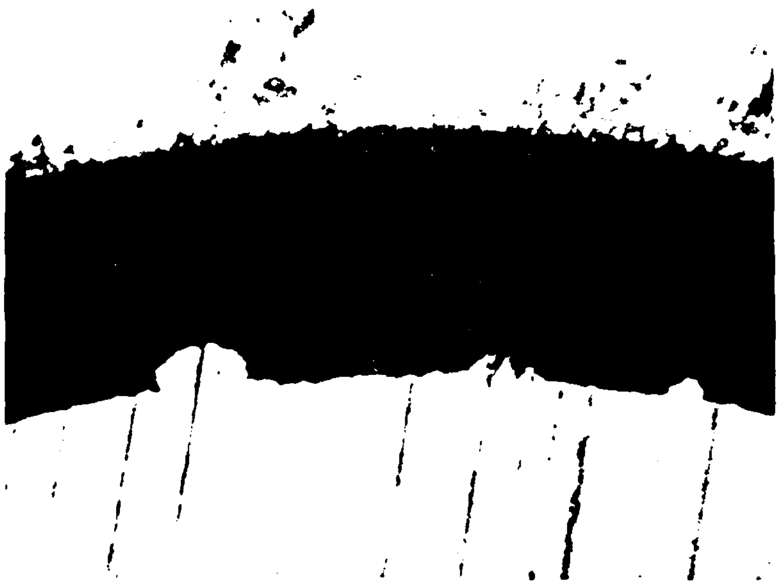

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Figure 9 Photomicrographs of a conductor coated with Hysol DK31-0711. A number of very small bubbles of maximum size 2μ may be seen throughout the epoxy. A few large bubbles up to about 20-30μ in diameter were observed to form at wire surface irregularities

Adherence and Flexibility: The four sample lengths were tested for adherence and flexibility according to the NEMA test requirements. After 30% elongation no cracks were observed. That is, the coatings all passed the specification requirement. Samples were also twisted and bent in both the hard and easy directions and again no cracks were detected.

Heat Shock: The heat shock resistance of the coatings was determined by exposing the samples for half an hour at various temperatures and then elongating according to NEMA requirements. Since no cracks were observed samples were given a post-bake treatment for half an hour at 240°C to determine if the epoxy had cured completely on the insulation line. No difference was noted between specimens as coated and those given the post-bake treatment. These results are given in Table III. All the specimens passed this test even up to exposure at 240°C (in air).

Oil Compatibility Tests: For these tests turbine oil that meets MIL-L-7808 specification requirements was obtained from Royal Lubricants Company, River Road, East Hanover, New Jersey 07936. For the tests the samples were placed in glass tubes about half filled with oil and then sealed. The tubes were then placed in ovens for the exposure tests for the time and temperature required. Two samples immersed in the turbine oil both before and after exposure are shown in the photograph in Fig. 10. In the preliminary exposure tests at 220°C in this oil the insulation swelled and the insulation was very rubbery. In addition, the oil after exposure was considerably darker in color. It was therefore decided to conduct tests on the oil in the as-received condition and after sample immersion and exposure at elevated temperatures.

The power factor and dc resistance of the oil was measured at 100°C. The data are given in Table IV. The aged samples (described in Table IV) were all exposed for 3 days at 220°C. The properties of typical commercial transformer oil are also recorded for comparison purposes.

TABLE III

HEAT SHOCK TESTS ON SAMPLES EXPOSED IN AIR AT VARIOUS TEMPERATURES

Stress Conditions Time	Temp.	Elongation	Equivalent NEMA Spec.	Samples A	B	C	D
1/2 hr.	150°C	30%	MW 18C	P*	P	P	P
1/2 hr.	180°C	15%	--	P	P	P	P
1/2 hr.	220°C	15%	MW 36C	P	P	P	P
1/2 hr.	240°C	15%	MW 20C	P	P	P	P

*P - Passed

Sample: A 3M As-coated

B 3M As-coated

C Hysol As-coated + 1/2 hr. at 240°C

D Hysol As-coated + 1/2 hr. at 240°C

Figure 10 Photograph of exposure test samples in the turbine oil. The left sample has been aged at 190°C while the right sample is in as-received oil.

TABLE IV

DIELECTRIC PROPERTIES OF TURBINE OIL

Sample	Power Factor	DC Resistivity at 100°C Ohm cm
Turbine Oil, As-received (no aging)	18.4%	$53.2x10^9$
Turbine Oil, 3 days at 220°C	99.6%	$1.05x10^9$
Turbine Oil, 3 days at 220°C with Hysol epoxy coated conductor	99.5%	$0.83x10^9$
Turbine Oil, 3 days at 220°C with Hysol epoxy coated conductor post-baked 1/2 hr. at 240°C	99.5%	$0.96x10^9$
Turbine Oil, 3 days at 220°C with 3M epoxy coated conductor post-baked 1/2 hr. at 240°C	99.4%	$0.95x10^9$
Transformer Oil	0.1%	$25x10^{12}$

It may be seen that the electrical resistivity of the turbine (lubricating) oil is considerably less than that of transformer oil. Also, the insulating properties of the epoxy are degraded after exposure to the oil. Even though the oil was in limited contact with air oxidation occurred and it seems likely that in the generator service environment that further degradation would occur. The power factor only increases slightly for the oil containing an insulated piece of wire. Therefore, most of the degradation may be attributed to oxidation; the epoxy coatings do not have much effect on the oil.

Some discussion on oil compatibility has been given in reference 11 . While the resistivity of the turbine oil is not as low as estimated (10^6 ohm cm at 100^oC) it is lower than transformer oil by several orders of magnitude and is lowered further on exposure to elevated temperatures. It is likely that the oil contains tricresyl phosphate, a highly polar compound, that lowers its effectiveness as an insulator.

As described above, samples of both epoxy coatings were immersed in the oil and exposed for 3 days at 220^oC. In both cases the coating thickness grew about 30-50% and the epoxy was rubbery and could be easily scraped off. The known plasticizing action of tricresyl phosphate is a likely contributing factor to the swelling that was noted. Examples of coated conductor exposed and then twisted are shown in Fig. 11. While both epoxies exhibit good properties in air neither can withstand the combination of high temperatures and resistance to the turbine oil.

B. Short Sample Tests

Following the observations of the oil compatibility tests it was mutually decided to make some trials with new high temperature polymers. As discussed previous development is continuing in this area and powders are available and samples were successfully coated with two polymers and another epoxy. The thermoplastic flow or cut-through temperature of these

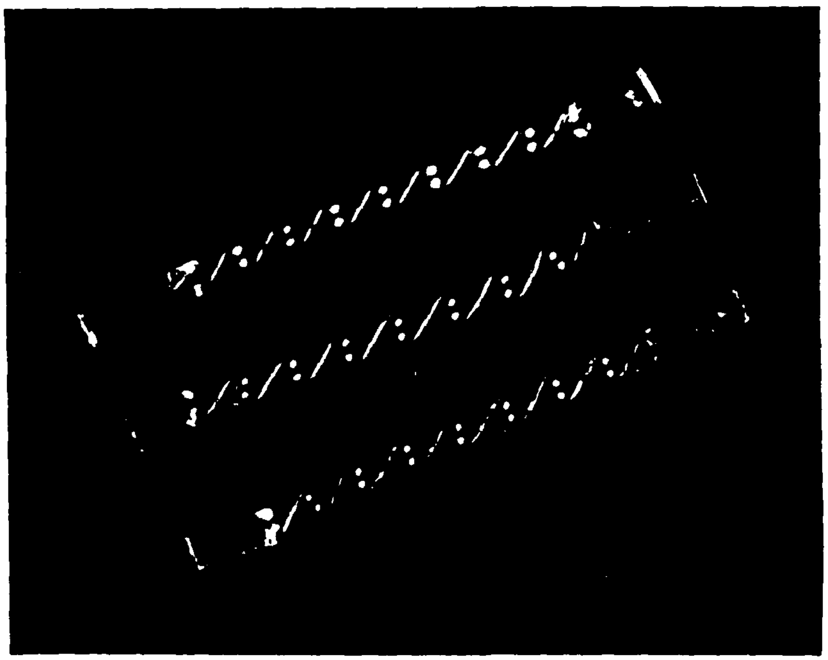

Figure 11 Twist samples after exposure in turbine oil for times and temperature shown below (top to bottom):

Hysol	1 day at 220°C
Hysol	1 day at 190°C
3M	1 day at 190°C

samples is given in Table V in both the as-coated condition and after exposure to the turbine oil for 1 day at 190°C. It may be seen that the PPS exhibited very promising results. The data should be interpreted as showing that the PPS is essentially not affected by the oil. The flexibility of PPS coatings at this point is probably not sufficient for the coil winding operation. However, formulation development to optimize flexibility and temperature resistance could lead to a very promising material.

A view of the apparatus for this test is shown in Fig. 12.

C. Electrical Tests

1) Pinhole Testing During the dimension measurement operation, pinhole frequency was also evaluated using Hipotronics Tester Model EW-4 at 250 volts dc. Neither of the conductors was found to be pinhole free as defined by a threshhold current of 5×10^{-6}A. The number of pinholes detected varied somewhat along the lengths.

Two conductor runs coated with MMM *and* Hysol *material involving* about 3300 feet were tested for pinholes. Accurate and meaningful pinhole count is difficult to obtain, however, comparative data was taken and shows a minimum of 1 pinhole per 30 feet of conductor, with the Hysol material showing a slightly lower pinhole count.

2) dc Dielectric Breakdown The air dc breakdown voltage of samples from the several lengths was then measured by wrapping aluminum foil around a six inch length of conductor and increasing the voltage until breakdown occurred. These results are listed in Table II (page 21). It may be seen that there is a considerable variation in breakdown strength probably resulting from the non-uniform coating thickness.

Four sample sections, two of each coating, were then selected for further testing.

TABLE V

THERMOPLASTIC FLOW OR CUT-THROUGH TEMPERATURE OF VARIOUS POLYMERS

Material	As-Coated Condition	After 1 day at 190°C in Turbine Oil
Epoxy	168°C	148°C
ETFE	191°C	151°C
PPS	276°C	284°C

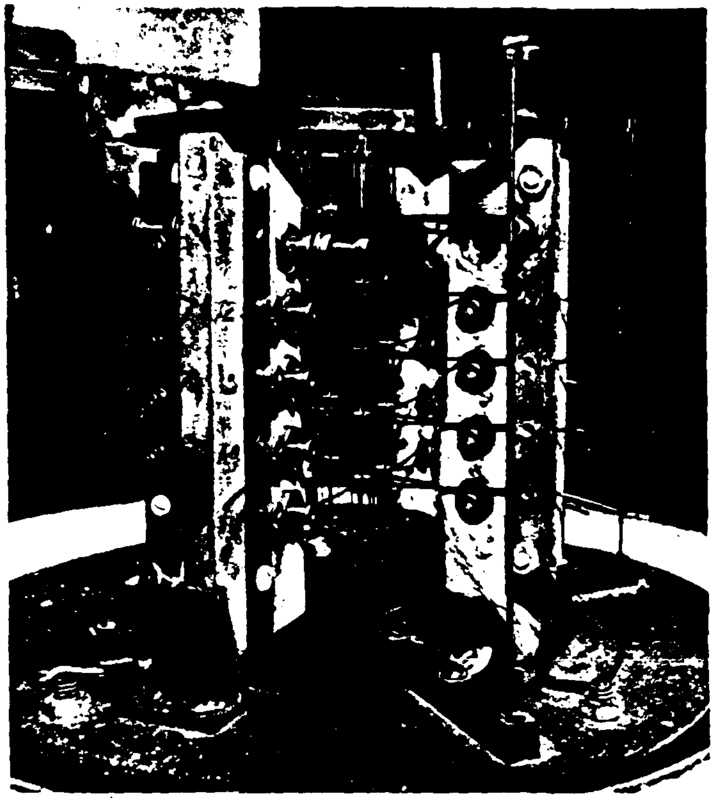

Figure 12 Views of apparatus used to measure Thermo-
plastic Flow (cut-through)

The air dielectric properties were measured on three samples of each length by a lead shot* method. The results are given in Table VI. The data shows reasonable correlation with the measurements made by the aluminum foil method. (*Using lead shot with an average diameter of 0.10 inches).

The samples were also tested in standard transformer oil for comparison purposes. These data are given in Table VI.

It should be noted that a more meaningful ac breakdown test was conducted as follows:

3) ac Dielectric Tests

Introduction: The electrical tests consisted of making measurements of CIV, CEV, and voltage breakdown of insulated conductor samples for comparative purposes. A total of 22 samples were tested (12 combinations of insulating materials, utilizing three methods of applying the insulation, electrostatic, solvent, and wrap).

The prime emphasis, however, was on testing various powder materials capable of being coated by means of the electrostatic process.

Test Procedure: Insulated conductor samples, 18" long, were individually mounted onto an aluminum ground plate, after immersion in electrical quality transformer (mineral) oil. A special oil resistent glass tape was used to secure the conductor sample conductor to the ground plate at two positions 3" apart (see Fig. 13).

The conductor samples were bent once at a 90^{0} angle as shown at each end, close to the point at which the samples were secured by the tapes so as to evaluate the ability of each insulation sample to withstand some flexing.

The conductor sample, mounted on the ground plate, was then immersed into an oil tank containing transformer grade mineral oil (see Fig. 14).

TABLE VI

AIR DIELECTRIC PROPERTIES OF
FOUR SELECTED SAMPLES MEASURED BY THE LEAD-SHOT METHOD

	Air Dielectric Volts	Transformer Oil Dielectric Volts
1	550	2900
	600	6400
	550	5700
	570 Average	5000 Average
2	950	6100
	1200	7500
	600	7000
	920 Average	6900 Average
4	1800	8300
	1000	8600
	1700	8400
	1500 Average	8400 Average
8	750	3000
	600	7100
	700	6600
	680 Average	5600 Average

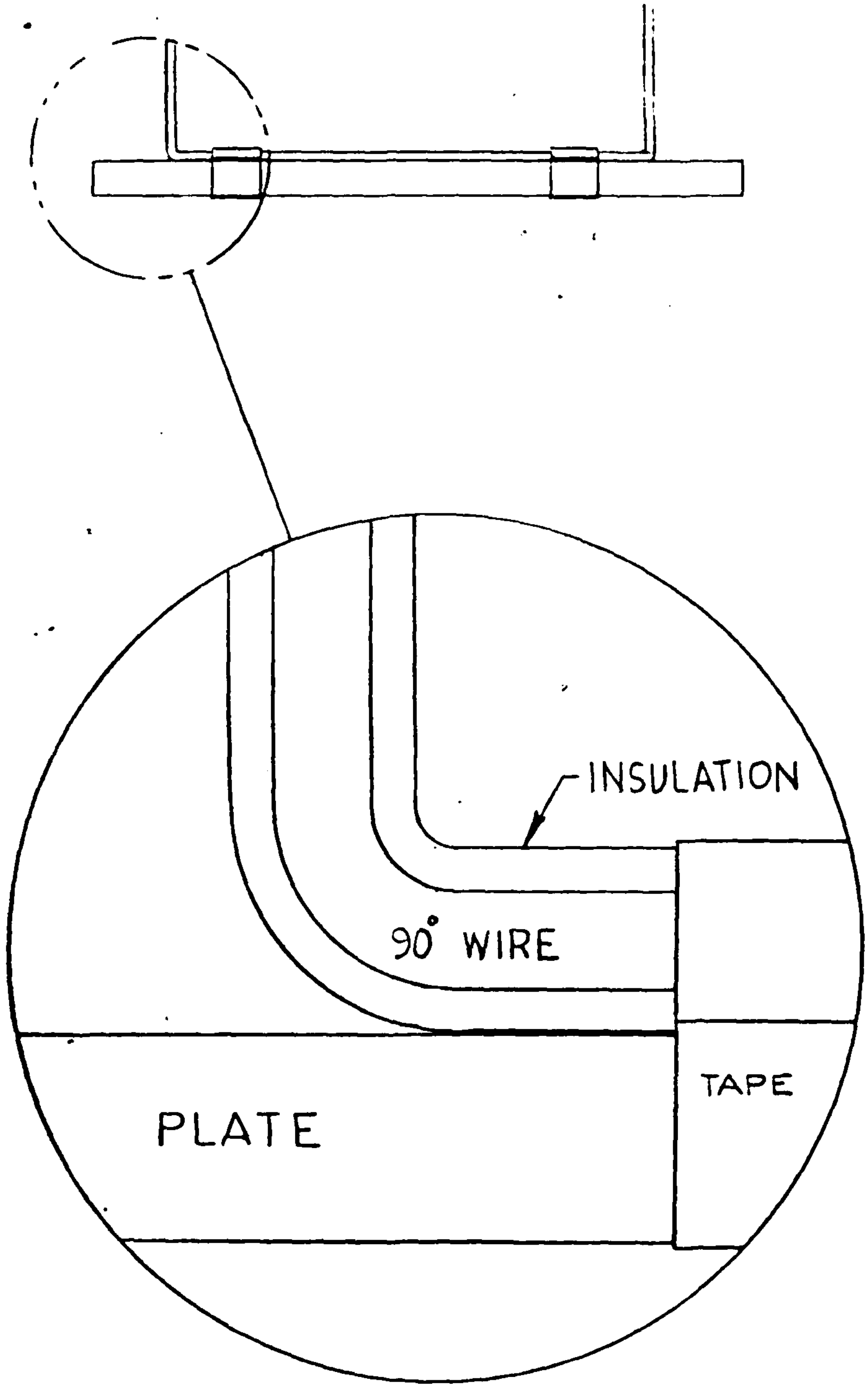

Figure 13

Schematic View of the Test Specimen and Aluminum Ground Plate

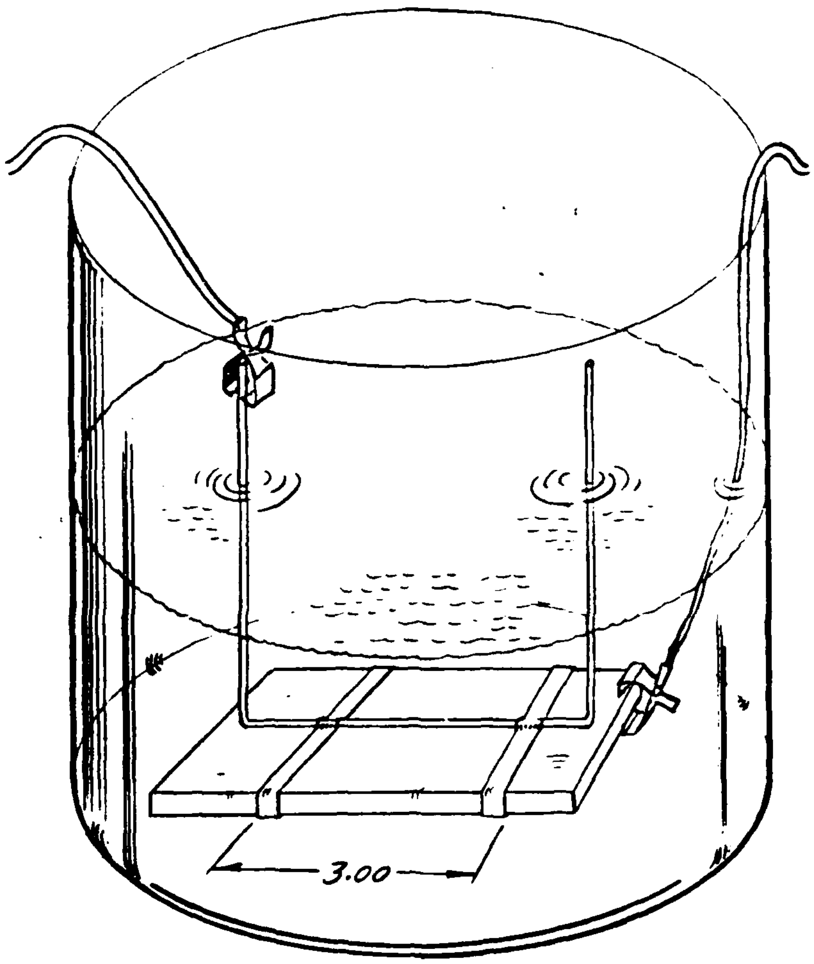

Figure 14

Schematic Diagram of the Sample Set-up for Electrical Tests

An ac voltage at 60 Hz was then applied at one end of the conductor with the aluminum plate grounded. This effectively stresses the conductor insulation and the small film of oil between the conductor and the ground plate and the voltage level was then raised slowly until the corona inception voltage was detected and noted. Corona detection tests were in accordance with ASTM-D1868 and are more fully described in Appendix E.

The voltage level was then reduced to detect and record the corona extinction voltage and finally the voltage level was increased slowly until a complete breakdown occurred.

Each sample was then removed and examined for the location of the breakdown and measured for minimum and maximum insulation thickness. All data were then converted to a volts/mil basis in order to evaluate the various samples on a uniform comparative basis.

Test Results: Tests were conducted on all of the samples as listed and identified in Table VII.

Actual test results on each sample for CIV, CEV, and E_B are also shown in Table VII.

Table VIII lists CIV, CEV, and E_B converted to a volts/mil on the maximum thickness basis.

Table IX shows a comparative ranking of each of the insulated conductors tested for CIV/mil and E_B/mil.

All but one sample conductor failed within the taped area at a point in closest proximity to the oil interface and ground plate.

In the case of rectangular conductor, the failures all originated at the closest radii corner to the ground plate. One sample (#16) failed outside of the taped area and at the point of the 90^o bend to the ground plate. All failures were clearly visible, showing carbon traces about the size of pinholes (see Fig. 15).

TABLE VII

RESULTS FOR CORONA INCEPTION VOLTAGE (CIV), CORONA EXTINCTION VOLTAGE (CEV), AND BREAKDOWN VOLTAGE (E_B)

SAMPLE	NAME	CIV	CEV	BREAKDOWN
1	3M-1	1430	0	0
2	3M-1	468	201	800
3	3M-2	1625	845	3510
4	3M-2	1690	1495	2211
5	Hysol #9	1625	1365	2900
6	Hysol #9	3250	2106	4160
7	Hysol-11	910	0	780
8	Hysol-11	1300	0	1300
9	Hysol-13	715	0	715
10	Hysol-13	715	0	715
11	ETFE	3185	2600	9360
12	ETFE	2730	1755	8840
13	ETFE	2002	1625	6240
14	Polymer	390	0	390
15	PPS	2340	1690	9750
16	PPS	2860	1300	7800
17	ETFE-FLT	1950	1170	7150
18	Polymer	1950	1495	5850
19	TEC	1560	520	4680
20	TEC	3250	2210	5070
21	Kapton F	1950	1365	5460
22	Kapton F	2795	1495	5720

MAXIMUM AND MINIMUM DIMENSIONS OF THE INSULATION OF THE ELECTRICAL TEST SAMPLES AND CIV, CEV, AND E_B VOLTS/MIL CALCULATED ON MAXIMUM INSULATION THICKNESSES

SAMPLE	NAME	MIN. THICK. (mils)	MAX. THICK. (mils)	Volts/Mil (Max. Thickness) CIV	CEV	E_B
1	3M-1	1.2	3.0	477	0	0
2	3M-1	1.1	3.0	156	67	267
3	3M-2	.7	3.2	508	264	1097
4	3M-2	1.4	3.4	355	440	650
5	Hysol #9	1.5	4.0	406	341	725
6	Hysol #9	1.3	4.2	774	501	990
7	Hysol-11	1.2	3.8	239	0	205
8	Hysol-11	1	3.0	433	0	433
9	Hysol-13	1	3.5	204	0	204
10	Hysol-13	.8	3.4	204	0	204
11	ETFE	5.5	8.4	379	310	1114
12	ETFE	3.6	4.0	683	439	2210
13	ETFE	1.2	2.5	801	650	2496
14	Polymer	.2	4.0			
15	PPS	3.6	6.6	360	260	1500
16	PPS	4	7.5	381	173	1040
17	ETFE-FLT	1.5	7.5			
18	Polymer	3.9	7.7			
19	TEC	.6	3.0	520	173	1590
20	TEC	.6	3.0	1083	737	1690
21	Kapton F	2	4.0	488	341	1365
22	Kapton F	2	4.0	699	374	1430

TABLE IX

INSULATION RANKING
BY SAMPLE NUMBER

LOW (RANKING) HIGH

	BREAKDOWN RANK (V/mil)		CIV RANK (V/mil)
13	ETFE	13	ETFE
19	Formvar	19	Formvar
15	PPS	3	3M Epoxy-2
11	ETFE	1	3M Epoxy-1
3	3M Epoxy-2	8	Hysol Epoxy #11
5	Hysol Epoxy #9	5	Hysol Epoxy #9
4	3M Epoxy -2	11	ETFE
8	Hysol Epoxy #11	15	PPS
7	Hysol Epoxy #11	4	3M Epoxy-2
9	Hysol Epoxy #13	7	Hysol Epoxy #11
1	3M Epoxy-1	9	Hysol Epoxy #13
RANGE	200V/mil to 2500V/mil		200V/mil to 1100V/mil

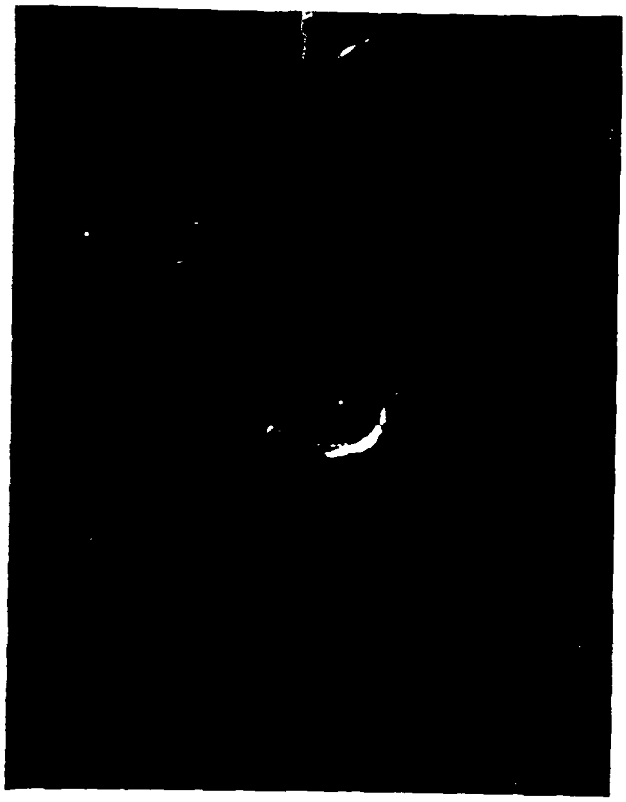

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Figure 15 View of a typical fault cavity produced at breakdown in the oil.

Cross-sections of each sample were made to evaluate the presence of voids and pinholes and to measure the variations of insulation over the conductor surface.

Figures 16-23 show the photomicrograph cross-sections for selected samples while Figures 24-28 show the insulation thickness data extrapolated from the cross-sections.

The variation in insulation thickness is graphically shown at the bottom of each figure by projecting the insulation thickness as a function of its radial position from the center of the conductor to the outer periphery.

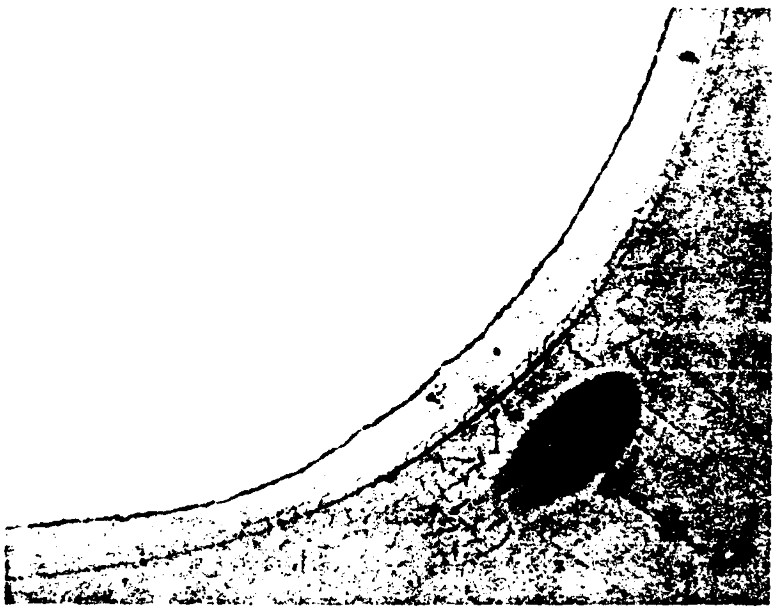
Discussion: All of the insulation samples tested (except sample #1) exceeded the statement of work criteria of 200-300 V/mil without breakdown and with minimum partial discharge. For that matter, all of the insulation samples (except sample #2) had corona inception voltage well above 200 V/mil. For rectangular conductors (sample 1-10), insulation thickness deposited varied from 1.1 to 3.8 mils over a given cross-section with a preferential (maximum) build-up at the bend radii in most cases. An average stress enhancement factor at the bend radii of about 2.5 is indicated for the improved conductor cross-section.

For rectangular conductors, void count ranged from 4 to 20 for a cross-section at the worst case quadrant. Sample #13, however, showed only one large void over its round cross-section.

Void sizes range from 1-6 microns which is well below the safe level for operation at 300 V/mil. The void size and population appear to be related to cure time and temperature as well as material.

A ranking of the insulation materials for overall void count, breakdown strength, and corona inception voltage would place sample #13 (ETFE) in first place, followed by sample #19 (Formvar), sample #3 (3M epoxy) and sample #5 (Hysol epoxy). Sample #15 (PPS) had a high void

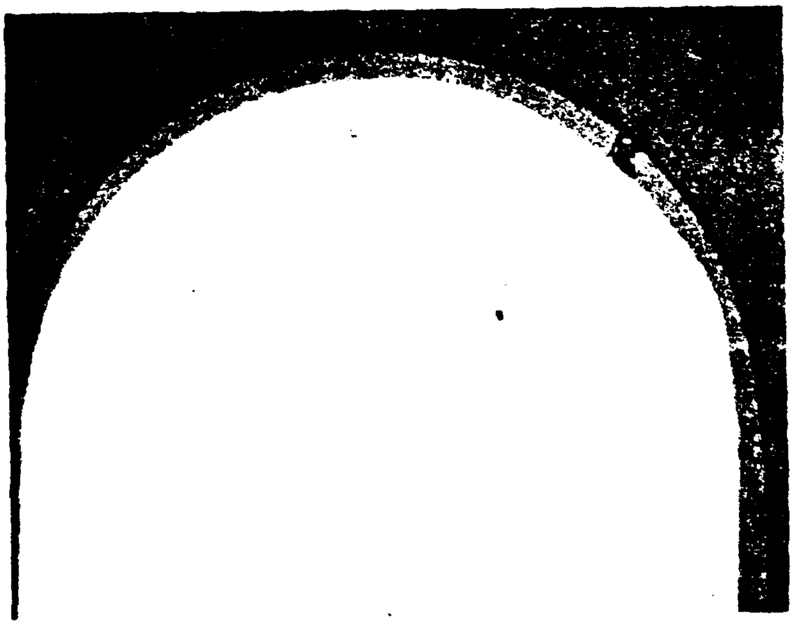
#1, 3M Epoxy 400X



#1, 3M Epoxy 200X

Figure 16 Photomicrographs of Sample #1, 3M Epoxy applied by electrostatic coating

#3, 3M Epoxy 100X



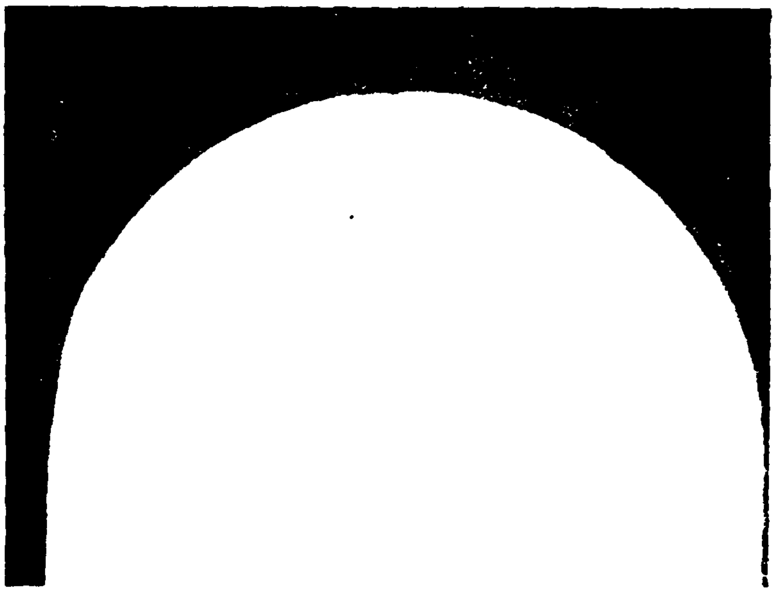
#3, 3M Epoxy 100X

Figure 17 Photomicrographs of Sample #3, 3M Epoxy applied by electrostatic coating

#4, 3M Epoxy 100X

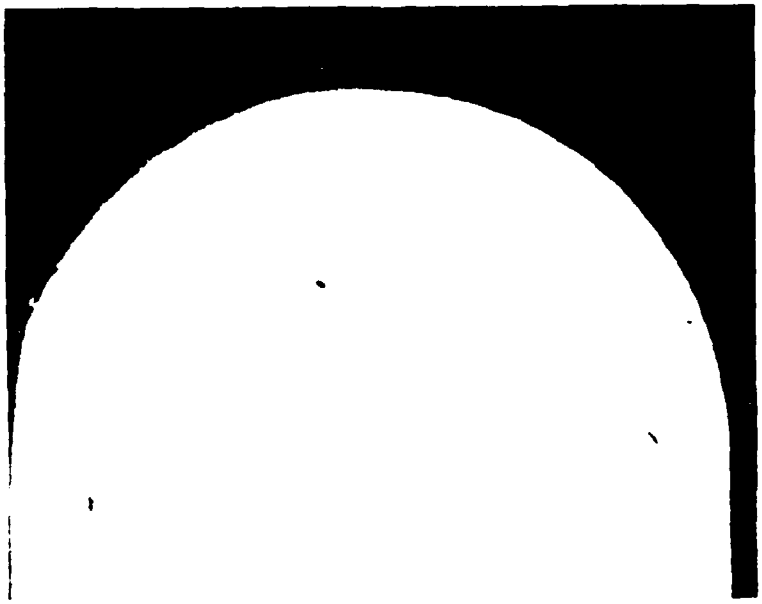
Figure 18 Photomicrograph of Sample #4, 3M Epoxy applied by electrostatic coating

#5, Hysol Epoxy 100X

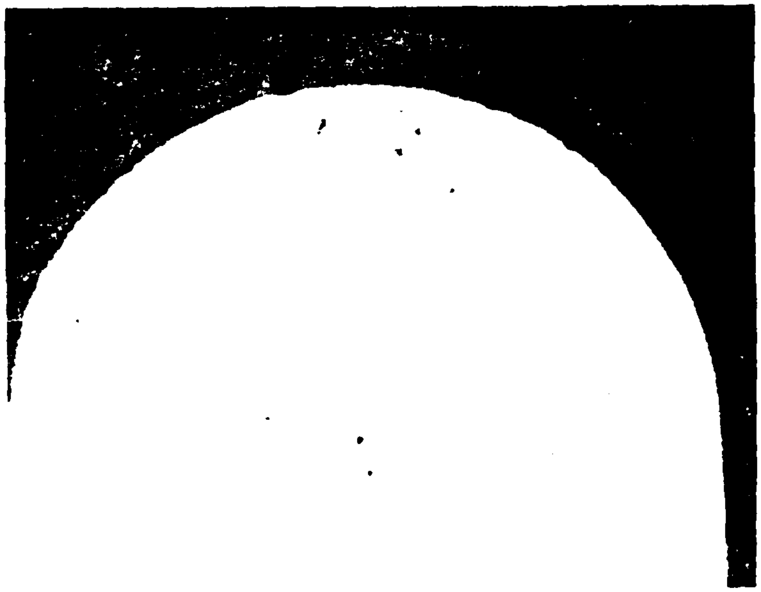


#7, Hysol Epoxy 100X

Figure 19 Photomicrographs of Samples #5 and 7, Hysol Epoxy applied by electrostatic coating

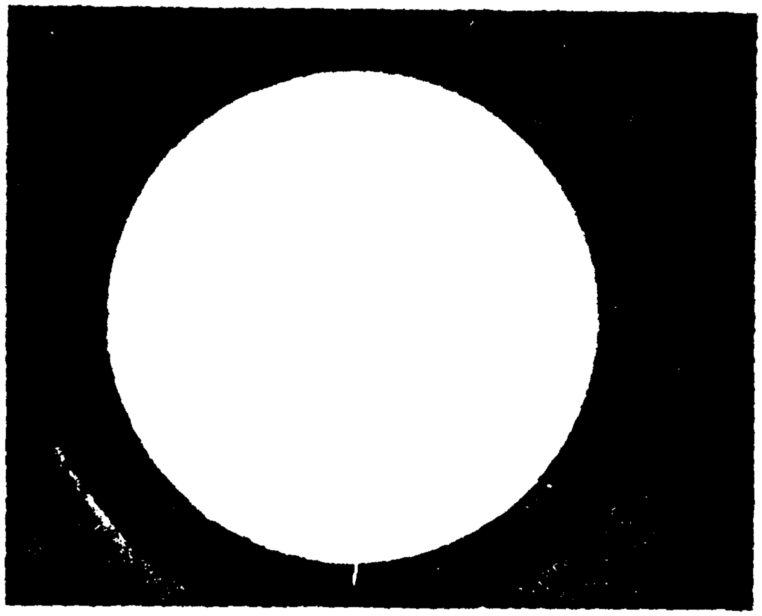


#8, Hysol Epoxy 100X



#9, Hysol Epoxy 100X

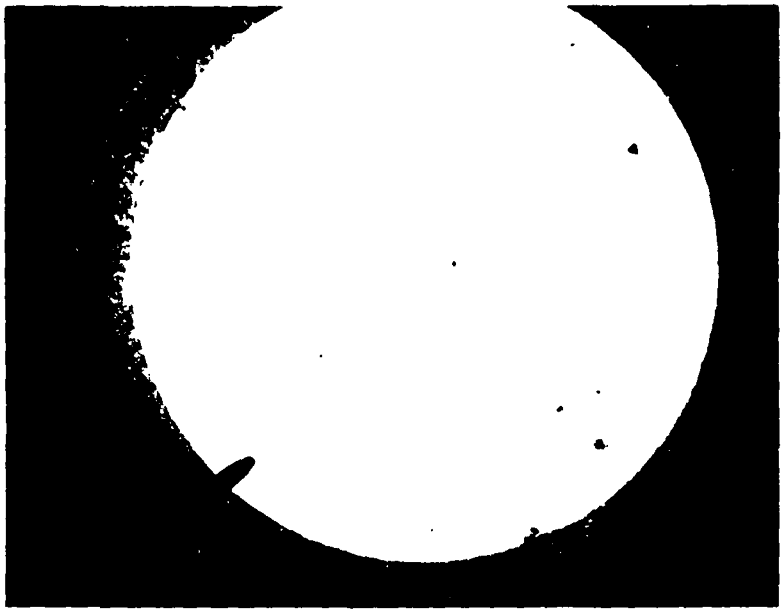
Figure 20 Photomicrographs of Samples #8 and 9, Hysol Epoxy applied by electrostatic coating



#11, ETFE 66X

#13, ETFE 100X

Figure 21 Photomicrographs of Samples #11 and 13, ETFE (Fluoroplastic) applied by electrostatic coating



#15, PPS 50X

#19, TEC-Formvar 200X

Figure 22 Photomicrographs of Sample #15, PPS applied by electrostatic coating and Sample #19, Superconducting Wire with a Formvar film insulation

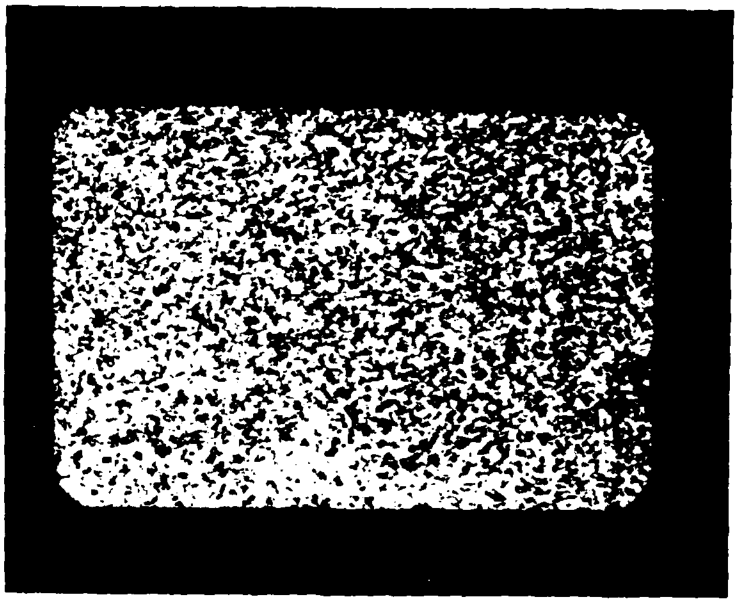


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Figure 23 Photomicrograph of Sample #22, Copper Conductor with 50% overlap Kapton-tape (150F019) wrapped

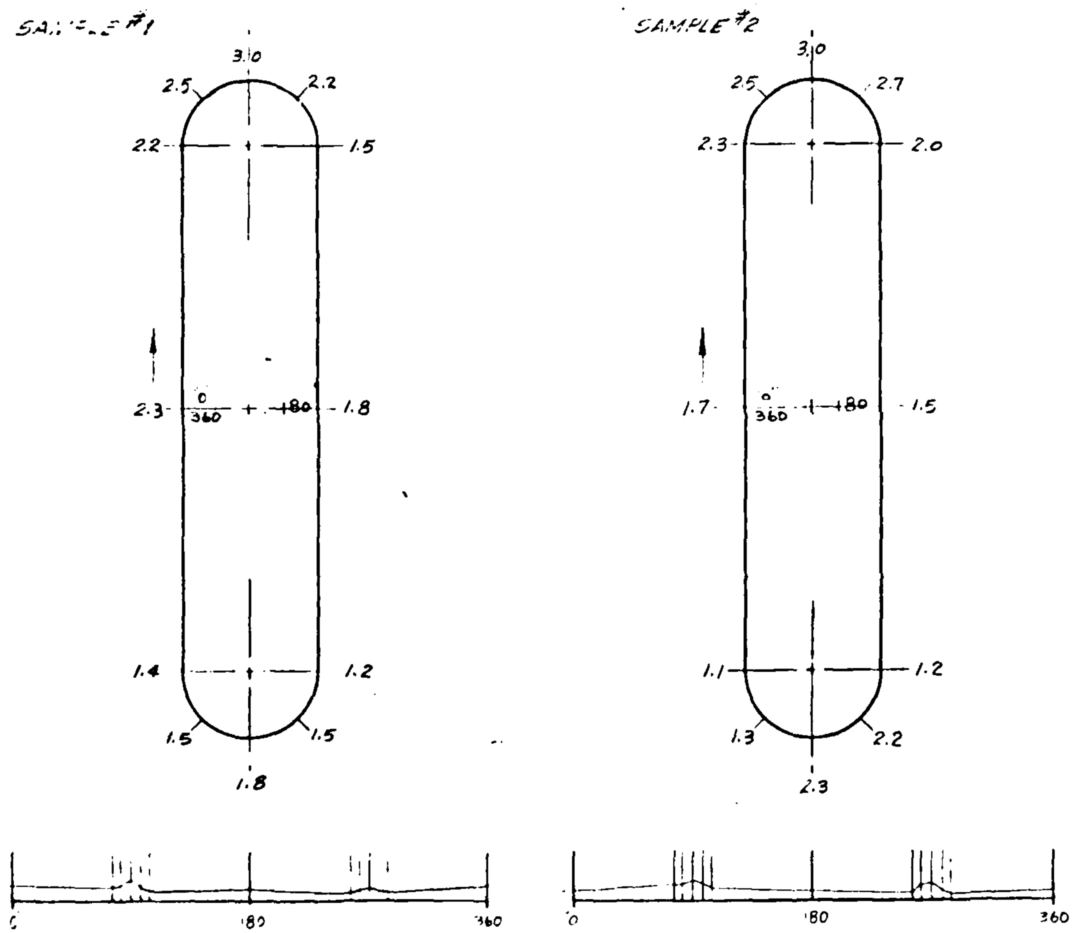

Figure 24
Thickness Profiles for Samples 1 and 2.

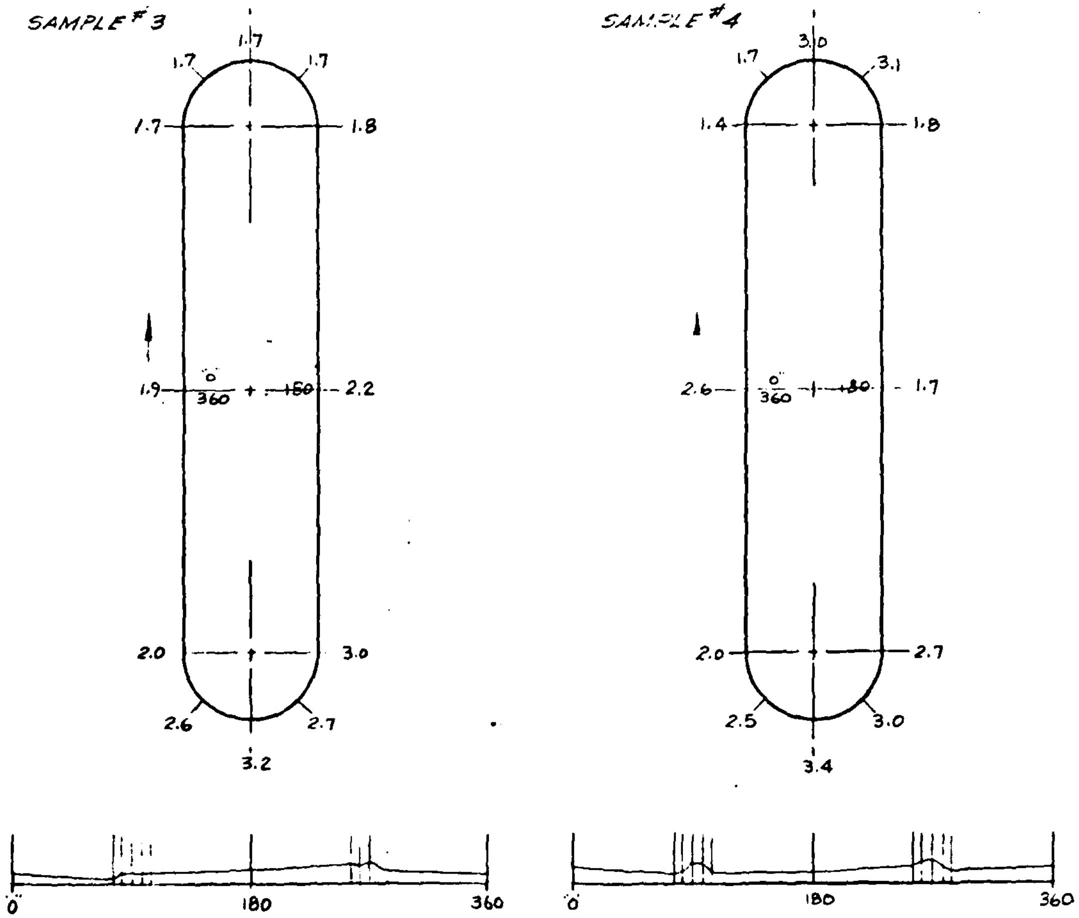

Figure 25
Thickness Profiles for Samples 3 and 4

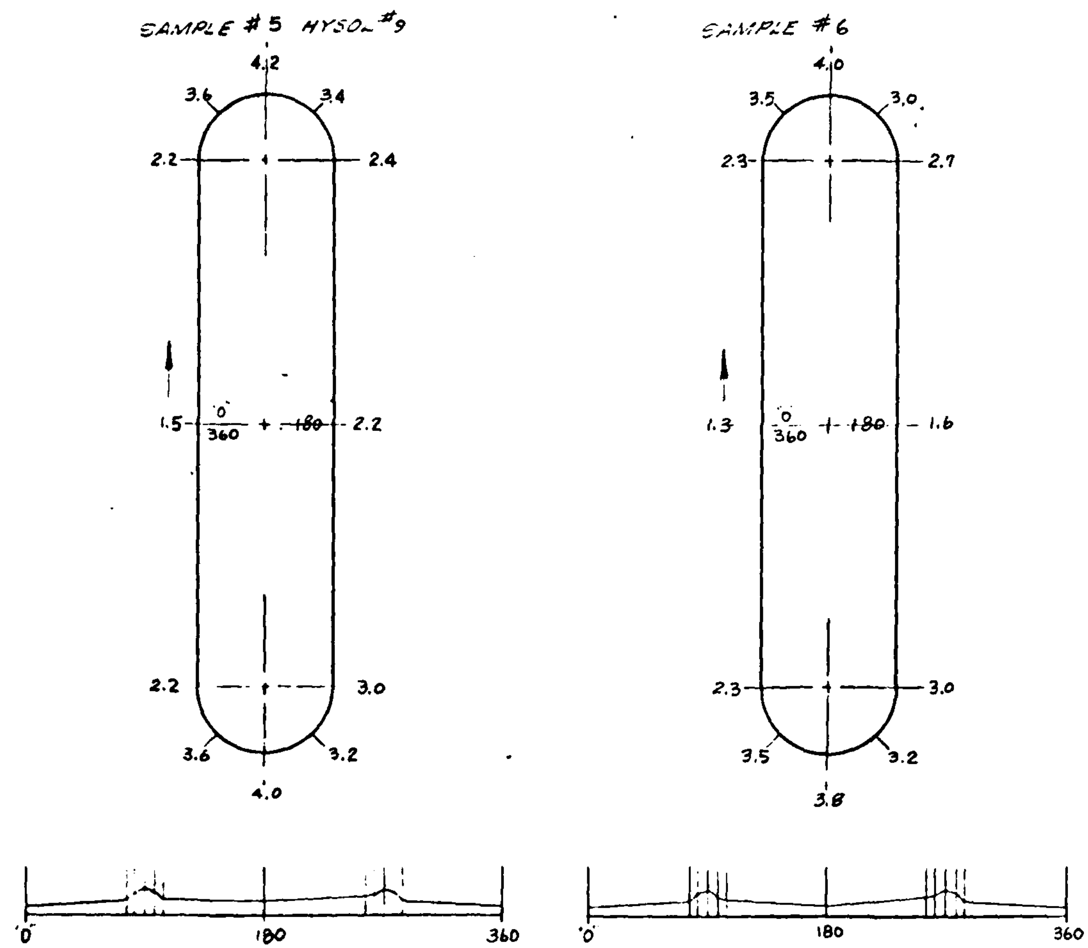

Figure 26
Thickness Profiles for Samples 5 and 6

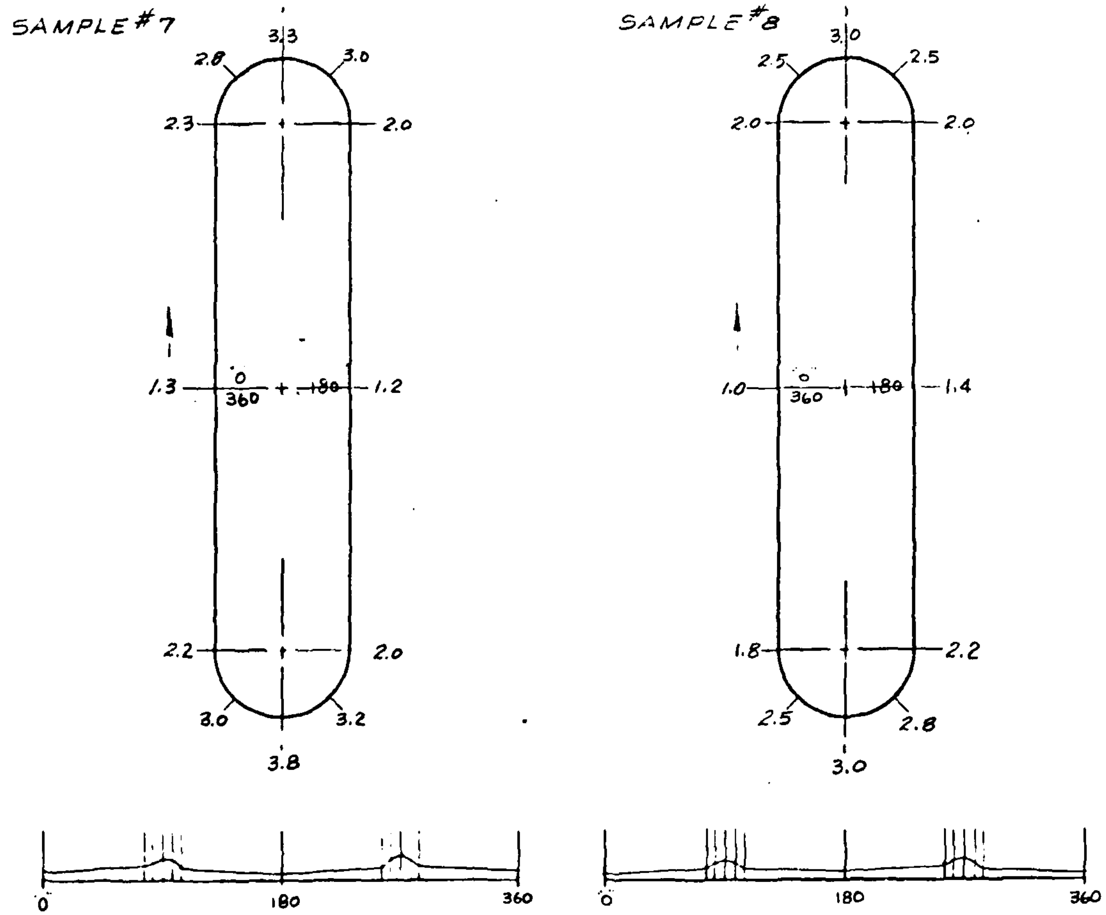

Figure 27
Thickness Profiles for Samples 7 and 8

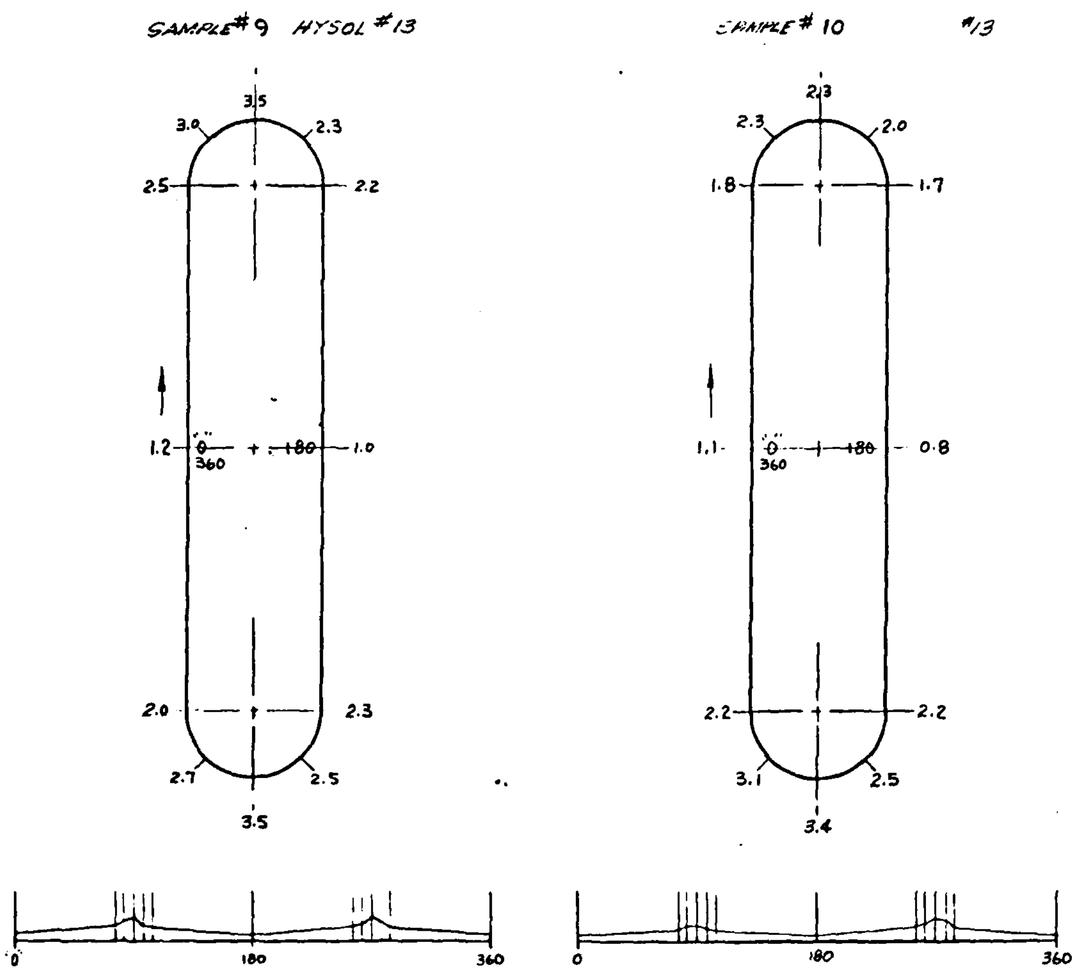

Figure 28

Thickness Profiles for Samples 9 and 10

population but otherwise would rank fairly high.

Significantly, all of the insulation materials testes exhibited breakdown strength results approaching those specified by the supplier when stress enhancement is considered.

V. CONCLUSIONS

A review of the fluidized bed electrostatic coating process and materials available for application to rectangular (flat) copper conductor has been made in accordance with the contract statement of work. From this investigation, the following conclusions may be drawn:

1. The process is capable of successfully applying coatings to copper conductor with a minimum thickness of .001 inch. Several commercial lines are running to insulate wire with epoxies for small and medium transformer applications. The process is gaining in importance because of lower energy costs and the elimination of pollutants inherent in film coating lines.

2. A number of classes of polymers are available for continuous coating. Epoxies have the highest temperature capability and chemical resistance. Trials with two epoxies show that they will withstand the temperature requirement (220°C) in air but cannot withstand the temperature in the turbine oil environment. The epoxies swell, lose adhesion, and become rubbery. Post-bake treatments of the epoxies did not improve their performance in the oil.

3. Trials with polymers applied by fluidized electrostatic bed batch processing showed that polymers are available with improved properties. However, these polymers cannot be currently applied continuously to wire because the process equipment used cannot accommodate the required long cure times that are often 30 minutes to 1 hour long. One material, polyphenylene sulphide (PPS) had a thermoplastic flow (cut-through) temperature of about 280°C after exposure to the turbine oil. In its present formulation, this polymer did not have much flexibility but shows promising ability to have the weaker properties modified to required levels.

4. In addition, it is very important to procure copper conductor with a good profile. It is essential that the radii at the edges of the wire blend uniformly into the flat faces and that no sharp (small radius) projections are present. In the program, MCA developed another source and rolled a long length of the conductor. This wire had a much better cross-section than the wire that is currently being used for the generator stator coils. In addition, MCA in-house work on rectangular superconducting wire has shown that the best cross-sections can be obtained by die drawing rather than rolling.

5. The turbine oil presently used in the generator is composed of chemicals that have a severe effect on most polymers particularly at elevated temperatures. Tri-cresyl phosphate, a usual component of the turbine oils made to military specification MIL-L-7808, is actually used as a plasticizer in lacquers and varnishes. If this oil remains as the cooling medium, new polymer development is necessary for electrostatic fluidized bed coatings. While, if another oil is substituted, additional oil compatibility testing is required.

6. Dielectric tests confirm that conductor insulation applied by the electrostatic coating method is capable of depositing a minimum of one mil of insulator over the entire surface of the conductor with a preferential build-up at the bend radii where it is needed. Dielectric strength and CIV values for most of the materials tested exceeded the requirements of the MERADCOM conductor specification as called out in the statement of work. Voids can be controlled, both in population and size so as to obtain the full insulation integrity of the basic coating materials, with improvements in the control of the curing operation.

VI. RECOMMENDATIONS

From the work accomplished it is evident that the electrostatic coating process holds promise for insulation of generator stator wire. However, no polymers presently commercially available for continuous application to wire have the combination of temperature resistance and compatibility to the turbine oil now used. Therefore, it is recommended that additional work be undertaken in the following principal areas:

1. Conductor with a smooth surface and edge radii that blend into the sides with no sharp points is essential to the production of a good insulation film. It is, therefore, recommended that further work be undertaken to produce wire with a good cross-section or profile.

   Die drawing has been proven to produce wire with the most uniform surface and cross-section. MCA has much experience in the drawing of copper matrix superconducting wire to exacting dimensions.

2. It is also recommended that development of high temperature chemically resistant polymers (compatible with the turbine oil/coolant and flexible for winding and insertion into the stator slots) be undertaken for application by the fluidized bed electrostatic coating process. A promising starting point is polyphenylene sulphide that presently requires a long curing time. Experimental work with PPS and other polymers on radiation curing (such as electron beam) could prove to be very fruitful. In this activity, further work should be done to optimize process parameters especially improved means of curing and to consider composite coatings such as PPS over epoxy to protect the epoxy from the solvent action of the turbine oil/coolant and to enhance the insulation properties.

3. An electrical analog of the composite candidate dielectric systems in the stator slot (conductor insulation, turbine oil/coolant and ground insulation) should be developed and tested so as to provide data to reduce the need for ground insulation, improve life, and improve the cooling of the conductors. Recognizing the poor dielectric properties of the turbine oil/coolant, the study should evaluate methods by which these may be used to advantage, i.e. stress grading.

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APPENDIX A

NOTES ON THE MAJOR COMPONENTS OF AN ELECTROSTATIC COATING LINE

The major components of a fluidized bed electrostatic coating line (see Figs. 2 and 3) are described in more detail below:

Cleaner: Ultrasonic cleaners have been found to be effective for cleaning wire at the high processing speeds employed. Ultrasonic transducers are used both for the detergent wash station and the rinse station. The wire is then dried with compressed air blown in the reverse direction to wire travel.

As discussed previously, work is continuing on process improvements in this area, in particular in-line fluidized bed annealing and cleaning.

Fluidized Bed Coater: The powder coating system consists of an electrostatic fluidized bed chamber,[12] with closed-loop powder management, and a feedback system to control deposition. Schematic diagrams of the coating chambers are shown in Figure A-1.

Dried air (dew point $< 32^{o}$) enters the coating chamber at the bottom and passes through a fine wire (metal wool mat) electrode. The electrode is charged with a high dc voltage, usually negative, that ionizes the air. In normal operation the voltage is usually in the range of 60,000-70,000 volts. The ionized air then passes through a porous plate (made from cast high density polyethylene with a 5μ pore size) that produces a fluidized bed of the polymer to be coated. The ionized air transfers a charge to the powder resulting in a charged powder cloud surrounding the wire above the fluidized bed. The wire at ground potential passes through the cloud and the powder adheres to the wire by electrostatic attraction. Coating is quite uniform because areas with a thinner initial coverage have a higher effective potential. Thus the system tends to self adjust to a

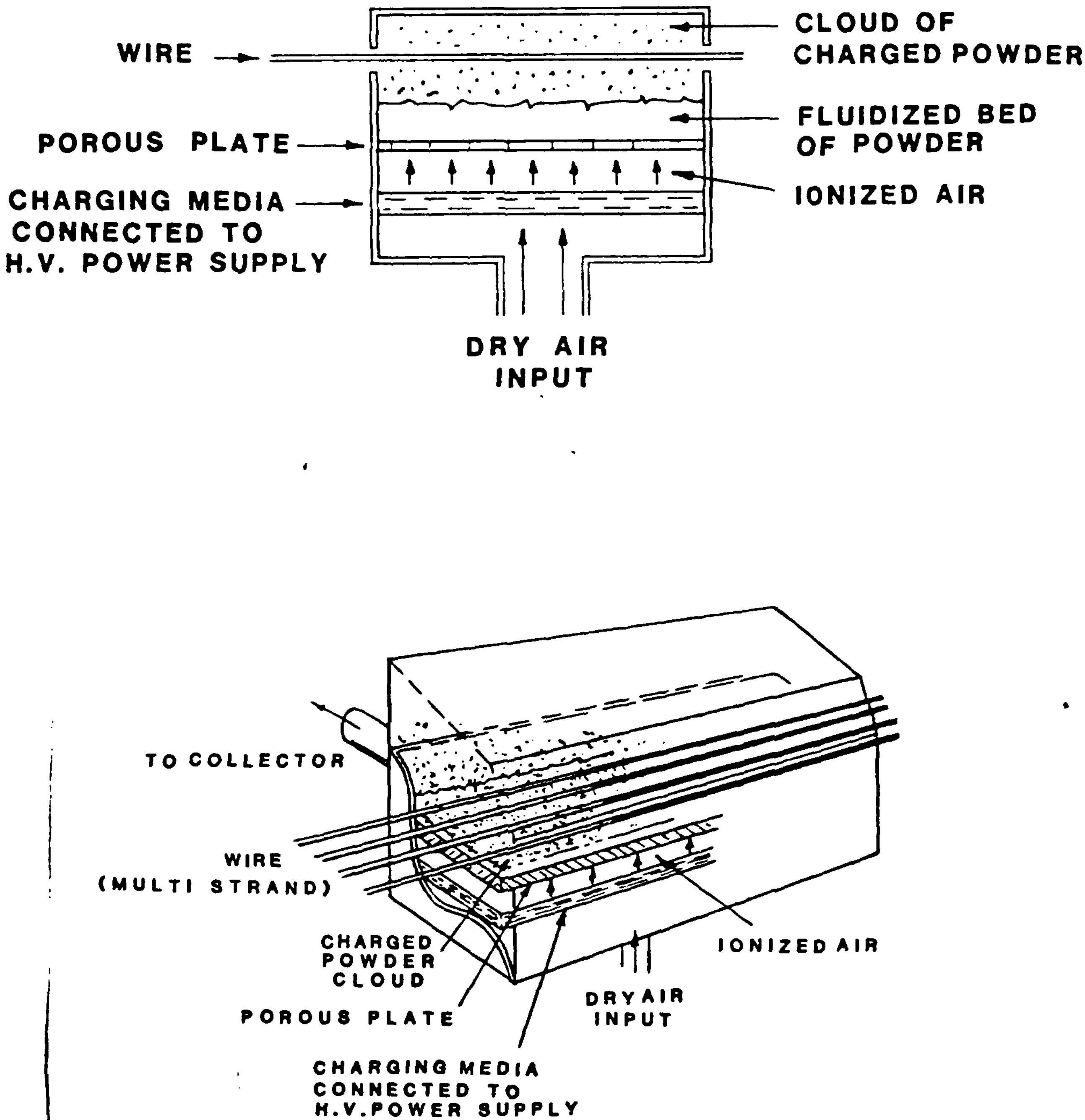


Figure A-1 SCHEMATIC OF ELECTROSTATIC WIRE COATING CHAMBER

uniform coating by voltage stress equalization.

Oven: The length of the oven is specified based on both the type of polymer to be used and to meet the line speed requirements. Recently installed production lines have 40 foot infrared convection ovens with separate temperature control in three zones up to $1000^{\circ}F$. Most of the cost reduction obtained in powder coating results from decreased energy use in curing. The use of powder coating also eliminates the energy needed for treating pollutants.

Wire Cooler: In present insulation wire lines the cured wire exiting the oven is directly cooled in a water bath. The insulation must be cool and have sufficient strength to prevent flow and damage when it passes over in-line pulleys. The epoxies presently used for insulating magnet wire have excellent flexibility and no degradation occurs as a result of the thermal shock encountered in the cooling tank.

Ancillary Equipment: The uncoiling and take-up equipment is of a standard nature. Level winding, i.e. careful layer winding with each turn adjacent to the next, may be used on take-up spools to prevent insulation damage.

Dimension measuring devices are usually incorporated for quality control purposes located immediately ahead of the take-up spool. Laser and other optical measuring systems have not in general proved to be too useful particularly on rectangular wire sections because of small wire movements. Direct contact rollers attached to linear differential transformers/transducers have been found successful. They provide a dimension measurement accuracy of about ±0.0005 inches.

Conventional pinhole testing equipment is also usually placed immediately before the take-up spool. The meter may be set at any desired voltage and be set to count the number of discontinuities.

Scotchcast® Brand
Electrical Resin 5256

One-Part, Epoxy Powder Resin

- **Excellent Flexibility and Elongation**
- **Good Electrical Properties**
- **Good Impact and Heat Shock Resistance**

"Scotchcast®" Brand Electrical Resin 5256 has been specially developed for continuous coating of wire products using the electrostatic fluid-bed coating process. It is also well-suited for applications where flexibility and resistance to cracking due to heat shock or impact are required. No. 5256 is manufactured by a fusion blend process which insures that each individual particle of powder contains all of the components necessary to effect a complete cure and attain the stated performance characteristics.

Typical Properties

*All values shown are typical. They are based on several determinations and are not intended for specification purposes.

Property	Value*
Color	Brown
Specific Gravity[1]	1.22
Impact Resistance[2] (Gardner, 1/8" steel panel)	> 160 in-lbs
Electric Strength (5-6 mil film)[3], volts/mil	1200
Dissipation Factor[4], %	
23°C 100 Hertz	0.5
150°C 100 Hertz	10
Edge Coverage[2] %	5
Gel Time @ 204°C (400°F)[2], seconds	35
Dielectric Constant[4]	
23°C 100 Hertz	3.8
150°C 100 Hertz	4.5

Typical Coated Wire Properties

Note: All tests performed on No. 10 square aluminum wire.
*All values shown are typical. They are based on several determinations and are not intended for specification purposes.

Property	Value*
Flexibility and Elongation[2]	No cracks at 15% elongation
Breakdown Voltage (5 mil total build)[3], volts	3000
Heat Shock[2] (90° bend, 4X mandrel, 350°F)	No cracks - 7-mil total build
Room Temp Bend[2] (90° bend, 4X mandrel, 75°F)	No cracks - 10-mil total build

Test Methods

[1]ASTM-D-792
[2]3M Test Method
[3]ASTM-D-149
[4]ASTM-D-150

Usage Information

Preparation and Application
Before applying resin 5256, make certain that the object to be coated is clean, dry and free of oils. Coating is accomplished first by charging the powder in an electrostatic fluid bed. The charged particles then repel each other and move upward forming a cloud above the surface of the bed. When a grounded object is passed through or placed in this charged cloud, it becomes coated.

Scotchcast resin 5256 can be deposited in film thicknesses of 2.0 to 15 mils on objects at room temperature. Because it is applied to a room temperature substrate, the powder can be selectively removed. Air used for fluidizing should be dried to -20°C (-4°F) dew point or lower.

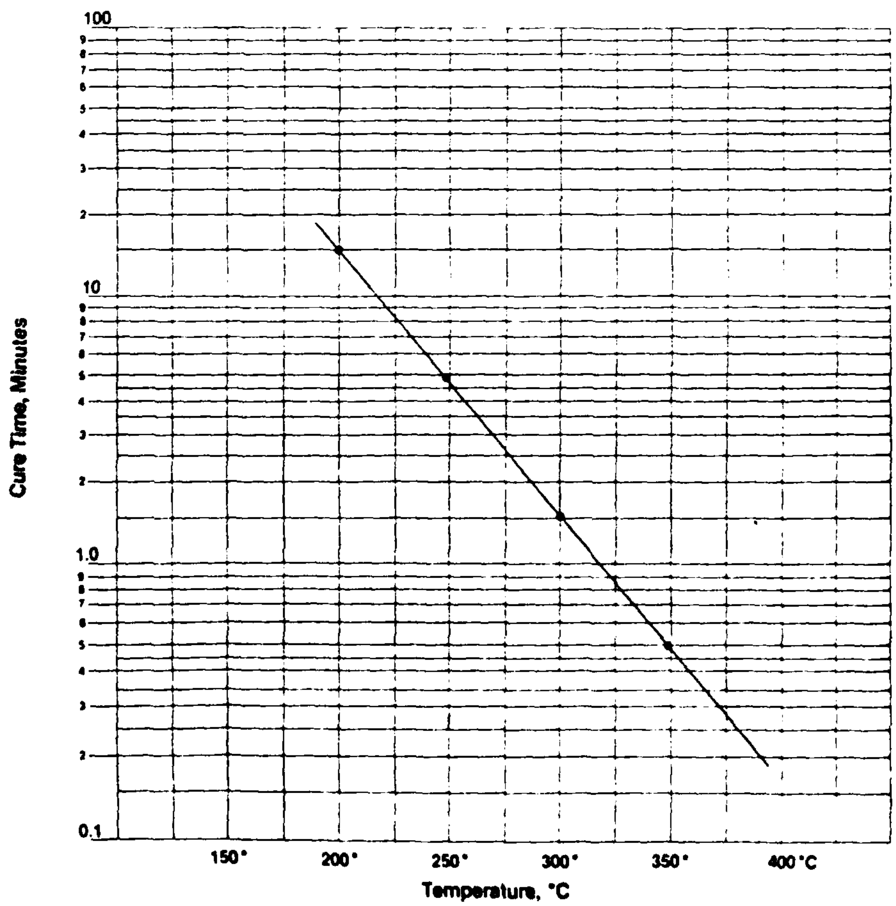
Curing is done by heating the coated unit to a temperature above the melting point of the resin. Resin 5256 melts, flows, gels, cures and bonds to the substrate. The result is a smooth, continuous coating.

Application Equipment
Equipment is available for processes utilizing manual or automated application techniques. Manufacturers' names can be suggested upon request.

Curing Guide
The cure of resin 5256 to a thermoset condition involves a time/temperature relationship. The graph of Cure Time vs. Temperature, below, provides nominal guidelines for obtaining the resin's adhesion, impact and chemical resistance characteristics. Times indicated by the graph do not include the interval needed for the part to reach cure temperature. The user must determine the time and temperature required, based on size and type of material to be coated.

Cure Time vs. Temperature

Scotchcast Brand 5256 Powder Resin



Handling Precautions

As with any finely organic material, dust clouds of resin can be ignited by open flames or electrical sparks. Resin dust collection equipment should be provided with adequate explosion release. Adequate ventilation should be provided and possible sources of ignition should be eliminated. To avoid build-up of static electricity, equipment should be grounded.

Inhalation of the dust or of vapors arising during cure should be avoided as much as possible. Use only in well-ventilated areas. Curing ovens should be vented to avoid vapor build-up in the work area. Many of the reactive materials used with epoxy resins have been reported to cause skin irritation and allergic skin reaction, particularly in sensitive individuals. If contact occurs, the skin should be washed with soap and water. Do not use solvent to remove resin from the skin. In case of eye contact, flush eyes immediately with water for at least ten minutes and call a physician.

Storage

Laboratory evaluation indicates that the usable shelf life of this product is six months from the date of shipment providing the material is stored in its original container at temperatures not exceeding 24°C (75°F). Carè should be taken when removing the resin from its original shipping container to prevent contamination. After the resin is removed, the bag should be retied immediately to avoid agglomeration caused by excess moisture. For best results, store in a cool (4°C or 40°F), dry place.

TECHNICAL INFORMATION

BULLETIN E8-0711

HYSOL®

DK31-0711

POWDER COATING FOR WIRE

1.0 DESCRIPTION

Hysol DK31-0711 is the first of a family of powder coatings for copper and aluminum wire. It was especially designed for use on wire or strap used in oil filled transformers. DK31-0711 was formulated for continuous exposure to temperatures up to 150°C.

Hysol DK31-0711 is suitable for application by electrostatic fluidized bed methods to attain film thicknesses down to 1 mil.

2.0 TYPICAL POWDER PROPERTIES

	Property	Test Method	Value
2.1	Gel Time @ 210°C, seconds	Hysol 10U	20-35
2.2	Glass Plate Flow, mm. @ 150°C		25-45
2.3	Particle Size Distribution		
	Thru 200 Mesh, %	Hysol 34D	100
	Thru 325 Mesh, %	Hysol 34D	80
2.4	Shelf Life, Months		
	@ 10°C	—	6
	@ 21°C	—	3

3.0 APPLICATION PROPERTIES

Min. Cure Time @ 190°C, minutes		15
Min. Cure Time @ 204°C, minutes		10

4.0 TYPICAL CURED FILM PROPERTIES

4.1	Specific Gravity	—	1.24-1.26
4.2	Impact Resistance, in.-lbs., OAR, 1-5 mil film	Hysol 44A	160 min.
4.3	Conical Mandrel Bend, ⅛ in diam., 1-4 mil film	—	Pass

5.0 ELECTRICAL PROPERTIES OF CURED FILM

5.1	Dielectric Strength, 1.5-2 mil film, v/mil @ 60 Hz	ASTM D149	1500-2000
5.2	Dissipation Factor, 1-4 mil film, 60 Hz	ASTM D150	
	@ 23°C		0.01
	@ 150°C		0.10

DIVISION HEADQUARTERS AND WESTERN PLANT 15051 E. DON JULIAN ROAD P.O. BOX 1282, INDUSTRY, CALIFORNIA 91749 PHONE 213-968-6511
EASTERN PLANT 211 FRANKLIN STREET OLEAN NEW YORK 14760 PHONE 716-372-6300
WESTERN PLANT 2850 WILLOW PASS ROAD PITTSBURG CALIFORNIA 94565 PHONE 415-[illegible]

6.0 STORAGE OF POWDER

Powders should be stored at 70°F (21°C) or below in closed containers. Storage areas should be air conditioned to minimize moisture. After removing powders from cool storage, allow to equilibrate with ambient temperature in closed containers before using to avoid moisture contamination.

7.0 SAFETY

WARNING! This product is irritating if inhaled. Avoid breathing vapor-dust. Use with adequate ventilation. This product is classified according to "Guides for Classifying and Labeling Epoxy Products According to Their Hazardous Potentialities" K68.1 published by American National Standards Institute, Inc., 1430 Broadway, New York, N.Y. 10018. See also bulletin G1-101 "Suggested Precautions for Handling HYSOL Epoxy Powders".

This powder contains organic resins and should be handled as a combustible dust. It can be ignited if suspended in air and in the presence of sparks or flames. Operations using powders should be set up in accordance with the National Fire Code* and the National Electrical Code.**

*Article 63, "Fundamental Principles for the Prevention of Dust Explosions in Industrial Plants," Volume II — National Fire Codes — Combustible, Solids, Dust, Chemicals and Explosives.

**Article 500 of the National Electrical Code.

8.0 HYSOL DK31-0711 is a developmental product and is subject to modification to meet specific usage requirements.

APPENDIX C

LIQUINITE COATING PRODUCTS

LNP

LIQUINITE© COATING POWDERS

FEP (Fluorinated Ethylene Propylene)

FEP is based on duPont's Teflon[1] FEP. It has the best electrical, chemical, friction and release properties of all Liquinite coatings. Continuous use temperature 400°F., short term 450°F., melt point 504°F. Highly stable in melt phase. Colors available.

ETFE (Ethylene Tetrafluoro Ethylene)

ETFE is based on duPont's Tefzel[1]. It has excellent electrical, chemical and high temperature characteristics. Good release properties. High flow in melt phase permits rapid curing. Continuous use temperature 350°F., short term 450°F., melt point 523°F. Colors available.

ECTFE (Ethylene Chlorotrifluoro Ethylene)

ECTFE is based on Allied Chemical's Halar[2]. It has excellent chemical, electrical and high temperature properties. Continuous use temperature 275°F., short term 375°F., melt point 460°F.

ECT Series (Pure ECTFE)

For thin build applications up to 12 mils

LMH Series (Modified ECTFE)

For heavier build applications. LMH series resins are self adhering and eliminates need for separate primer coat.

PVF_2 (Polyvinylidene Fluoride)

PVF_2 is based on Pennwalt's Kynar[3] and Kreha's KF[4] polymer. It has excellent corrosion resistance, good chemical and high temperature properties. Very hard damage resistant fluoropolymer coating. Excellent electricals. Easiest to apply of all Liquinite fluorocarbon coatings. Proprietary powder primer adheres to most metals including stainless steel. Continuous temperature 275°F., short term to 300°F., melting point 327°F. It complies with FDA and USDA requirements.

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UNITED KINGDOM
LNP Plastics U.K., 92-94 Church Road
Mitcham, Surrey CR4 3 TD/01640-0046

LNP ENGINEERING PLASTICS

C2778

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PPS (Polyphenylene Sulfide)

PPS is based on Phillip Petroleum's Ryton[5]. It possesses fluoropolymer type chemical and temperature characteristics with improved mechanical properties. Crosslinks during cure at 700°F. Continuous use temperature 425°F., short term 600 to 700°F. after curing. Melt point 530°F. before cure. No true melt point after cure.

PPS/PTFE

Grades of PPS modified with PTFE are available for improved friction, wear and release properties and physical and temperature properties.. It is similar to unmodified polymer. Some grades comply with FDA. Extremely resistant to sand and grit abrasion.

Thermoplastic Polyurethane

Thermoplastic Polyurethanes are resilient, high energy absorbing polymers recommended for use where tough, rugged damage resistant coatings are required.

Aliphatic polyether type standard, however, aromatic and polyester combinations also available for special applications. Thermoplastic polyurethanes exhibit excellent resistance to wear, abrasion, errosion and mechanical impact type damage. Recommended for use in abrasive slurries and dry particulate matter. Material also possesses good outdoor weatherability and can be used on structural iron and other areas where abusive treatment is likely. Available in a variety of colors.

Special Coatings

LNP also formulates special combinations of coating powders where specialized properties are required. May we help solve your tough engineering problems? Prices and availability upon request.

1 Registered trademark of DuPont
2 Registered trademark of Allied
3 Registered trademark of Pennwalt
4 Registered trademark of Kreha
5 Registered trademark of Phillips Petroleum

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Thermoplastic Polyurethane

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4 Registered trademark of Kreha
5 Registered trademark of Phillips Petroleum

L PROPERTI[illegible] OF LIQUINITE® HI-PERFORMANCE COATING POWDERS

PROPERTY	FEP FEP Series	ETFE ETF Series	ECTFE ECT Series	Modified ECTFE LMH Series	PPS PPS Series	PPS/PTFE PPS Series	PVF2 PVF Series	Polyurethane LPU Series
Specific Gravity	2.15-2.16	1.70-1.71	1.67-1.68	1.68	1.34-1.35	1.37-1.38	1.77	1.15
Coverage (sq ft/lb/mil)	89	112	114	115	143	139	108	178
Thickness, mils								
Per cycle* (by ESP)	1-3	2-4	3-6	3-6	2-6	2-6	3-6	2-6
Total (max.)	10-15	10-15	12-15	25-30	20-30	20-30	30-40	30-40
Cure Temp., °F	625-675	600-650	500-550	525-600	690-750	690-750	450-500	375-400
Cure Time (min.)								
Base & Interim Coats	5-10	2-3	2-3	2-3	10-15	10-15	5-6	3-5
Final Coat	60-120	5-10	5-10	5-10	60-90	60-90	15-20	5-10

Heavier builds can be obtained when coating hot part.

PROPERTY	FEP	ETFE	ECTFE	Modified ECTFE	PPS	PPS/PTFE	PVF2	Polyurethane
MECHANICAL PROPERTIES								
Hardness								
Durometer, Shore D	55	75	80	78	86	85	80	54
Rockwell R	45	50	93	85	124	122	110	-
Impact Strength								
Gardner (in.-lb.)								
Face	160	>160	>160	>160	160	160	>160	160
Reversed	160	>160	>160	[illegible]	160	160	>160	160
Tensile Strength (psi)	2,200	6,500	6,600	[illegible]	10,800	10,600	6,900	8000
Tensile Elongation (%)	10-20	150-250	170-200	50-75	1-2	1-2	100	300
THERMAL PROPERTIES								
Melting Point (°F)	500-504	522-524	460-464	450-51[illegible]	505-510(1)	505-510(1)	327	310
Max. Service Temperature (°F)								
Continuous	400	350	275	[illegible]	425	425	275	150
Short-Term	450	475	350	3[illegible]	[illegible]	700	300	225
Thermal Conductivity (Btu-in./hr-sq ft-°F)	1.4	1.65	1.05		[illegible]	1.95	1.7	
Specific Heat (Btu/lb-°F)	0.28	0.46	0.45		0.2[illegible]	0.26	0.2	
Flammability								
Oxygen Index (%)	95	31	60	5	[illegible]	46	45	
FRICTION, WEAR & RELEASE								
Friction								
Static	0.03-0.04	0.3-0.5	0.4-0.6	[illegible]	0.25-0.35	0.15-0.14	0.14	0.65-0.95
Dynamic	0.04-0.06	0.3-0.4	0.4-0.5	[illegible]	0.24-0.30	0.13-0.15	0.18	0.65-0.95
Wear								
Weight Loss, Tabor (mg) CS 17 Disc, 1-kg Load								
100 cycles	2.2	2.8	2.4	–	2.7	1.1	–	
1,000 cycles	14.8	13.4	11.1	11.5	24.0	6.4	5.0	<1.0
Release								
Critical Surface Tension	17.0	26	31	31	[illegible]	23	25	

(1) Before cure - resin crosslinks during cure resulting in coating with no true melting point.

This information is based on our experience to date and we believe it to be reliable. It is intended only as a guide for use at your discretion and risk. We cannot guarantee favorable results and assume no liability in connection with its use or the use of the products described. None of this information is to be taken as a license to operate under, or a recommendation to infringe, any patents.

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LNP
ENGINEERING PLASTICS

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LIQUINITE
COATING PRODUCTS

LNP

P.D CP3-582

Supersedes 3-279
May 1982

ETFE (Ethylene-Tetrafluoroethylene)

Ethylene-tetrafluoroethylene (ETFE) copolymer exhibits a high level of mechanical strength and toughness and at the same time closely approaches the chemical and electrical properties of fully fluorinated polymers. Its versatility is illustrated by the ease with which a wide range of build-up (thin and thick) can be achieved, reducing application costs. Thin films of 2-3 mils are being employed to protect products from metal contact and contamination. Thick films have been used for protective linings in corrosive chemical environments. Lined shipping containers, storage tanks, valves, pipes and reactors are illustrations of these applications. The excellent electrical properties of ETFE have led to its use as an insulating material for a wide variety of electrical and electronic applications.

Any substrate that can be evenly heated to 550°F. without releasing volatiles can be coated with ETFE. LNP offers ETFE coating powders in natural color for single step or multiple application primerless coatings. Customer colors available on request.

Application Technique		Liquinite Grade No
Fluid Bed:	Regular Flow	ETF-1010
Electrostatic Spray:	Regular Flow	ETF-2001
	High Flow	ETF-3001

PROPERTIES

ETFE (ethylene-tetrafluoroethylene) is one of the most recent members of the fluoropolymer family. It is a partially fluorinated material designed to give increased toughness with little sacrifice in chemical, electrical, or release properties. Chemical resistance is intermediate between FEP and chlorine-containing fluoropolymers. It is subject to chemical attack by oxidizing acids and chlorine, and to a lesser degree, aliphatic primary amines at temperatures above 212°F. These properties are detailed in the LNP brochure entitled *"Comparative Chemical Resistance of High Temperature Thermoplastics."*

Although ETFE has a higher melt temperature than FEP it has a lower viscosity at melt point and may be processed at lower temperatures. It will withstand continuous use temperature of up to 350°F. and even short term exposure to temperatures of 470° F. under dynamic conditions. Under static conditions these short term limits may be extended 25°. ETFE is resistant to radiation up to 100 megarads.

TYPICAL PROPERTIES OF LIQUINITE® ETFE COATINGS

PHYSICAL PROPERTIES	
Specific Gravity	1.70
Bulk Density (gms/liter)	535-550
Coverage (sq.ft./lb./mil)	112
THERMAL PROPERTIES	
Melt Range (°F.)	520-524
Continuous Use Temperature (°F.)	350
Short Term Use Temperature (°F.)	475
Specific Heat (BTU/lb./°F.)	0.46
Thermal Conductivity (BTU/hr./sq.ft./°F/in.)	1.65
Melt Index (360°C. - 1200 g load) (gms/10 min.)	30-40
WEAR AND FRICTIONAL PROPERTIES	
Coefficient of Friction	
Static	0.3-0.5
Dynamic	0.3-0.4
Taber Weight Loss from Revolving Disc (1 kg load, 5 mil coating)	
CS 17 Wheel - 100 Cycles	2.8
1000 Cycles	13.4
Release Properties	
Critical Surface Tension (dynes/cm)	26
Contact Angle, Water	
Contact Angle, Hexadecane	

MECHANICAL PROPERTIES	
Hardness - Durometer (shore)	D75
Rockwell	R50
Gardner Impact Strength (ft.-lbs.)	
Face	>160
Reverse	>160
Tensile Strength, psi	6500
Elongation, %	100-300
Flammability	
U.L. Subject 94	94V-0
Oxygen Index	30
ELECTRICAL PROPERTIES	
Dielectric Strength (25°C. - 60 Hz)	
1 mil	5000
4 mils	3500
20 mils	1200
Volume Resistivity (25°C. - 175°C.) (ohms/cm)	10^{17}
Dielectric Constant (60 Hz - 2 x 10^9 Hz)	2.6
Dissipation Factor (60 Hz - 2 x 10^9 Hz)	$0.6\text{-}3.0 \times 10^{-3}$
Surface Resistivity (25° C.)	
50% R.H. (ohms/sq.)	5×10^{14}
Arc and Track Resistance (secs)	75

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APPLICATION OF LIQUINITE ETFE

The choice of coating technique is dependent on the application, part configuration and equipment available. The following is a brief selection guide. A chemical resistance table should be consulted if applicable.

1. Prevention of Metal Contamination
   Electrostatic 2-5 mils
2. Intermittent Exposure to Chemicals at Room Temp.:
   Electrostatic 8-12 mils
3. Intermittent Exposure to Chemicals at High Temp.:
   Electrostatic 10-15 mils
   Fluid Bed 10-15 mils
4. Continuous Exposure to Chemicals at Room Temp.:
   Electrostatic 15-25 mils
   Fluid Bed 15-25 mils
5. Release Applications:
   Electrostatic 2-3 mils
6. Wear Applications:
   Electrostatic 15-25 mils
   Fluid Bed 15-25 mils
7. Applications Involving Sharp (>12 gauge) Edges:
   Fluid Bed and
   Electrostatic Fluid Bed
8. Cylinders, Tubes, Pipes:
   Electrostatic
   Fluid Bed
9. Applications with Highly Variable Thickness:
   Fluid Bed with Induction Heating

PART PREPARATIONS

Unless all surfaces are thoroughly degreased and sandblasted, poor adhesion can result. Typical preparation for light metals is sandblasting at 60-75 psi with 100-200 mesh alumina, flintshot or quartz. Steel and cast iron should be prepared with 50-100 mesh. Parts should not be handled after surface preparation. If a great deal of time has elapsed between surface preparation and application, the part should be heat cleaned at 700°F.

All edges should be rounded or stresses in the coating can be created. This can result in shrinkage from the edge, exhibited by cracking or poor bonding in these regions.

ELECTROSTATIC TECHNIQUE

A. Suggested voltage - 70-90 kV
   Charge - negative (optional)

B. Thin Films (1.5-3.0 mils)
   Spray the part cold until powder ceases. Cure time is part dependent, but surface should be at 600-650 °F. for 5-10 minutes. Cold water quenching is not recommended. Remove part from oven and allow to air cool.

C. Heavy and Multiple Coats (4-30 mils)
   Preheat the part to 650 ° F. Spray the part until material does not melt. Return to 600° F. oven until material melts (2-3 minutes). Build is part dependent but usually in the 4-6 mil range. Immediately after melt remove the part from the oven and respray the part hot. The program should be repeated until desired build is achieved. Final cure is 4-8 minutes at 550-600°F. Remove part from oven and allow to air cool.

   IMPORTANT - ETFE fluoropolymer will not withstand sustained periods in the melt stage without thermal degradation. Therefore, rapid cures are not only desirable from a time and labor standpoint but from a quality standpoint as well. Over cure coatings exhibit discoloration.

FLUIDIZED BED APPLICATION

Bed should be thoroughly cleaned of other materials. ETF 1001 utilizes normal fluidization pressure (3-7 psi). Bulk density in fluid suspension is 27.6 pounds/ft.^{3}

> Agitation or vibration may be required to initiate fluidization. Preheat part to obtain surface temperature of 600-620°F., when immersed in fluid bed. Immersion time is 2-10 seconds depending on desired build and part configuration. Return part to 600°F oven for 2-3 minutes (between coats), 4-8 minutes for final coat.

PATCHING

For surfaces that cannot be covered by rejigging and secondary powder applications, the following technique is recommended:

> Heat the exposed area with infrared or hot air gun, apply powder over the area and reheat until smooth coating is obtained. Avoid degradation of polymer and inhalation of fumes.

For patching of metal, use LNP Filler F-1000.

STRIPPING

ETFE can most effectively be removed by heat stripping at 1000°F. Bake-off time is 2-3 hours. Scraping can also be facilitated by the use of a blow torch. This should always be done in a well-ventilated area. The fumes are toxic on long term exposure.

TROUBLE SHOOTING

Sagging:	This is caused either by too high a bake temperature or excessive build.
Discoloration:	This is caused by either excessive exposure at curing temperature, or too high a cure temperature.

CAUTION

Avoid inhalation of powder. Keep curing ovens well-ventilated. ETFE gives off toxic fumes about 750 ° F. Smoking materials should not be allowed where ETFE is handled. Torches and burnoff techniques should not be employed for stripping.

LIQUINITE COATING PRODUCTS

LNP

P.D. CP2-582

Supersedes 2-279
May 1982

FEP (Fluorinated Ethylene-Propylene)

Applications for fluorinated ethylene-propylene include chemically resistant, and low friction coatings for valve components, ball floats, pumps, filters, ball bearings, and processing equipment of all types. In electrical equipment, coatings may be applied to coil slots in motor starters, armature cores, transformer coils, insulator posts, masks for circuit boards, etc. Any substrate that can be heated to 700°F. without releasing volatiles can be coated.

LNP currently offers a standard FEP coating powder which is designed for primerless coatings. The natural color is transparent. Custom colors are available upon request.

Electrostatic Spray

FEP-2101 Food Grade, Natural

PROPERTIES

FEP is well-known for its outstanding chemical resistance at temperatures up to 450°F. These properties are detailed in the LNP Brochure entitled "Comparative Chemical Resistance of High Temperature Thermoplastic Coatings". In general, the only materials known to attack FEP are fluorine, molten alkali metals, and metallo-organics like sodium naphthalene and butylithium. These are all exotic chemicals.

FEP has the lowest coefficient of friction of any powder coating material - 0.04. It also has the greatest release properties of all the fluorocarbons with a critical surface tension of 17.0 dynes/cm. FEP exhibits remarkable electrical stability over an extremely wide frequency range.

TYPICAL PROPERTIES OF LIQUINITE® FEP COATINGS

PHYSICAL PROPERTIES	
Specific Gravity	2.15-2.16
Bulk Density (gms/liter)	575-600
Coverage (sq.ft./lb./mil)	89
THERMAL PROPERTIES	
Melt Range (°F.)	500-504
Continuous Use Temperature (°F.)	400
Short Term Use Temperature (°F.)	450
Specific Heat (BTU/lb./°F.)	0.28
Thermal Conductivity (BTU/hr./sq.ft./°F./in.)	1.4
Melt Index (372°C. - 5 kg load) (gms/10 min.)	70-85
WEAR AND FRICTIONAL PROPERTIES	
Coefficient of Friction	
Static	0.03-0.04
Dynamic	0.04-0.06
Taber Weight Loss from Revolving Disc, mg	
CS 17 Wheel - 100 cycles	2.2
1000 cycles	14.8
Release Properties	
Critical Surface Tension (dynes/cm)	17.0
Contact Angle, water	100°
Contact Angle, hexadecane	46°
MECHANICAL PROPERTIES	
Hardness - Durometer (Shore)	D55
Rockwell	R45
Gardner Impact Strength (ft.-lbs.)	
Face	>160
Reverse	>160
Tensile Strength, psi	2200
Elongation, %	10-20
Flammability - U.L. Subject 94	94V-0
Oxygen Index	95
ELECTRICAL PROPERTIES	
Dielectric Strength (25°C. - 60 Hz)	
1 mil (volts/mil)	7000
4 mils (volt/mil)	4000
20 mils (volts/mil)	1700
Volume Resistivity (25°C.-175°C.) (ohms/cm)	10^{18}
Dielectric Constant (60 Hz-2 x 10^9 Hz)	2.1
Dissipation Factor (60 Hz-2x10^9Hz) (60 Hz - 2 x 10^9 Hz)	0.2-1.2x10^{-3}
Surface Resistivity (25°C.)	
40% R.H. (ohms/sq.)	10^{16}
80% R.H. (ohms/sq.)	10^{14}
Arc and Tract Resistance	
FEP does not arc or track	>160 secs

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APPLICATION OF LIQUINITE FEP

The choice of coating technique is dependent on the application, part configuration and equipment available. The following is a brief selection guide. Chemical resistance tables should be consulted if applicable.

1. Intermittent Exposure to Chemicals at Room Temp.:
   Electrostatic 5-10 mils
2. Intermittent Exposure to Chemicals at High Temp.:
   Electrostatic 10-12 mils
3. Continuous Exposure to Chemicals at Room Temp.:
   Electrostatic 10-12 mils
4. Release Applications
   Electrostatic 4-6 mils
5. Coefficient of Friction Applications:
   Electrostatic 4-6 mils
6. Cylinders, Tubes, Pipes:
   Electrostatic

PART PREPARATIONS

Unless all surfaces are thoroughly degreased and sandblasted, poor adhesion can result. Typical preparation for light metals is sandblasting at 60-75 psi with 100-120 mesh alumina, flintshot or quartz. Steel and cast iron should be prepared with 50-100 mesh. Parts should not be handled after surface preparation. If a great deal of time has elapsed between surface preparation and application, the part should be heat cleaned at 700°F.

All edges should be rounded or stresses in the coating can be created. This can result in shrinkage from the edge, exhibited by cracking or poor bonding in these regions.

ELECTROSTATIC APPLICATION

A. Suggested Voltage - 70-90 kV
   Charge - negative (optional)

B. Thin Films (2-5 mils)
   Spray the part cold until powder transfer ceases or desired thickness is obtained. Cure time is dependent, but surface should be at 625-700°F. for 30-60 min. Cold water quenching is optional and can be used to achieve maximum adhesion and resistance to cracking at sub-freezing temp.

C. Multiple Costs
   Apply first coat as described. The part should be removed from the oven and sprayed hot to achieve 4-6 mil builds. Larger builds are not recommended. The part should then be returned to a 625-700°F. oven for 15 minutes. Follow the same program for subsequent coats. The final coat, however, should be cured at 625-700°F. for 15 minutes, then the temperature should be reduced to 575°F. and held for 30 to 60 min. The maximum recommended thickness should not exceed 12 mils.

PATCHING

For surfaces that cannot be covered by rejigging and secondary powder applications, the following technique is recommended:

Heat the exposed area with infrared or hot air gun, apply powder over the area and reheat until smooth coating is obtained. Avoid degradation of polymer and inhalation of fumes.

For patching of metal, use LNP Filler F-1000.

STRIPPING

Heat stripping should not be used, as poisonous fumes are liberated. The best technique is to cross-hatch one inch squares over the surface of the part with a sharp implement. Put the part in warm (100° F.) 10% acetic acid overnight. This will remove about 1/'0 mil of metal and allow for easy scraping of the FEP.

TROUBLE SHOOTING

Bubbles: This is usually caused by entrapment of air in the viscous FEP. It generally results from excess build of powder. Try reducing build. If this does not work, hold part at 540° F. for 30-45 minutes at beginning of cure cycle.

Bubbles can also be caused by degradation of FEP at excessive temperatures. This results in reduction of film strength and poor appearance as well. Correct by reducing processing temperatures to within recommended limits.

Another source of bubbles could be due to the *presence of moisture. Usually poor powder transfer or fluidization characteristics are also evident.* Spread powder on trays (maximum thickness not to exceed one inch) and dry powder at 230°F. for four hours.

Water Marks: This is caused by quenching FEP in water at temperatures above 550 ° F. If water quenching is desired, the part should be dipped quickly in and out of water until cool.

Sagging or Running: This results from 1) too high a cure temperature, 2) excessive build, or 3) irregular coverage. Temperature should be reduced toward low side of recommended cure cycle. Rotating the part *during cure is also recommended.*

Cracking and Poor Adhesion: Factors influencing cracking and adhesion are surface preparation and curing. Parts should be thoroughly degreased and sandblasted. Excessive curing temperatures will degrade polymer causing embrittlement. Impact and adhesion are promoted by making the resin more amorphous. This can be accomplished by rapid cooling of the part (i.e., water quenching).

Storage: Powders should be stored only in closed containers in a cool, dry environment. Open containers increase the chance of contamination and introduction of moisture.

CAUTION

Avoid inhalation of powder. Keep curing ovens well ventilated. FEP gives off toxic fumes about 750°F. Smoking materials should not be allowed where FEP is handled. Torches and burnoff techniques should not be employed for stripping.

LIQUINITE COATING PRODUCTS

LNP

P.D. CP1-582

Supersedes 1-279
May 1982

PPS (Polyphenylene Sulfide)

Polyphenylene Sulfide (PPS) is used for chemical and wear applications where high modulus and cut-through resistance are required.

PPS coatings are found where chemical or abrasion resistance is required. This high modulus coating has been employed for wire and thread guides, molds, housings, driers, valves, stirrers, and reactor linings. Combined with polytetrafluoroethylene (PTFE) it produces substrates with low coefficient of friction and good wear resistance.

High builds of PPS can be achieved with single temperature bake cycles. All grades are primerless. Any substrate that can be heated to 700°F. without releasing volatiles can be coated.

LNP currently offers four standard PPS coating powder grades. The natural color is black (dark brown in very thin coatings). Colors are not available. Higher flowing grades are available on request.

Application Method	FLUID BED or ELECTROSTATIC SPRAY	
Low Flow:	General Purpose	PPS-1001
	PTFE Lubricated	PPS-1002
Regular Flow:	General Purpose	PPS-2001
	PTFE Lubricated	PPS-2002

PROPERTIES

The high modulus of PPS lends it stiff metal-like characteristics. It is a cross-linkable aromatic thermoplastic. This allows PPS coatings to withstand high temperatures and a wide range of chemical environments. It has a continuous use temperature of 425°F. and can be exposed short term to temperatures of 700°F. it has perhaps the best chemical resistance of the non-fluorinated thermoplastics. Details are discussed in the LNP Brochure entitled "Comparative Chemical Resistance of High Temperature Thermoplastic Coatings". Oxidizing acids like nitric and perchloric and chlorinated aromatic solvents like chlorobenzene are representatives of the two main classes of chemicals which affect PPS the most aggressively.

The durability of PPS is greatly augmented by the addition of PTFE. The standard PTFE lubricated grades offer two to three times the wear life of the unmodified base material. After preliminary wear contact the coating approaches the coefficient of friction of PTFE. The release properties of the PPS are also significantly enhanced. The composite coating maintains the strength and resistance of polyphenylene sulfide.

TYPICAL PROPERTIES OF LIQUINITE® PPS COATINGS

	PPS	PPS with Lubricant
PHYSICAL PROPERTIES		
Specific Gravity	1.34-1.35	1.37-1.38
Bulk Density (gms/liter)	550-585	570-600
Coverage (sq.ft./lb./mil)	143	139
THERMAL PROPERTIES		
Melt Range (°F.)	525-530*	
Continuous Use Temp. (°F.)	425	
Short Term Use Temp. (°F.)	700	
Specific Heat (BTU/lb./°F.)		
Thermal Conductivity (BTU/hr./sq.ft./°F./in.)	2.0	
Melt Index 300°C. - 1200 gm. load (gm/10 min.)		
Electrostatic Grades	30-40	
Fluid Bed Grades	8-16	
Lubricated Grades	-	25-35
WEAR AND FRICTIONAL PROPERTIES		
Coefficient of Friction		
Static	0.30	0.17
Dynamic	0.24	0.15
Taber Weight Loss from Revolving Disc (CS 17), mg		
100 cycles	1.7	1.1
1000 cycles	19.0	6.4
Release Properties		
Critical Surface Tension (dynes/cm)	34	23
Contact Angle, Water	79°	

	PPS	PPS with Lubricant
MECHANICAL PROPERTIES		
Hardness - Durometer (Shore)	D86	D85
Rockwell	R124	R122
Gardner Impact Strength (ft.-lbs.)		
Face	160	
Reverse	160	
Tensile Strength, psi	10,800	
Elongation, %	1-2	
Flammability - U.L. Subject 94	94V-0	94V-0
Oxygen Index	44	46
ELECTRICAL PROPERTIES		
Dielectric Strength (volts/mil)		
1 mil	4500	
4 mils	2300	
20 mils	1150	
Volume Resistivity (ohms/cm)	10^{16}	
Dielectric Constant - 1 KC	3.11	
1 MC	3.22	
Dissipation Factor - 1 KC	0.0004	
1 MC	0.0007	
Arc Resistance (secs)	160	

*Before curing (no true melt point after cross linking)

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APPLICATION OF LIQUINITE PPS

The choice of coating technique is dependent on the application, part of configuration, and equipment available. The following is a brief selection guide. A chemical resistance table should be consulted if applicable.

1. Intermittent Exposure to Chemicals at Room Temp.:
   Electrostatic (Grade 2001) 8-12 mils
2. Intermittent Exposure to Chemicals at High Temp.:
   Electrostatic, (Grade 2001 or 1001) 10-15 mils
   or Fluid Bed 10-15 mils
3. Continuous Exposure to Chemicals at Room Temp.:
   Electrostatic, (Grade 2001 or 1001) 15-30 mils
   or Fluid Bed 15-30 mils
4. Release Applications:
   Electrostatic (Grade 2002) 5-8 mils
5. Coefficient of Friction Applications:
   Electrostatic, (Grade 2002 or 1002) 5-8 mils
   or Fluid Bed 10 mils
6. Wear Applications:
   Electrostatic, (Grade 2002 or 1002) 15-25 mils
   or Fluid Bed 15-25 mils
7. Applications Involving Sharp (>12 gauge) Edges:
   Fluid Bed and
   Electrostatic Fluid Bed
8. Cylinders, Tubes, Pipes:
   Electrostatic
   Fluid Bed
9. Applications with Highly Variable Thickness:
   Fluid Bed with Induction heating

PART PREPARATIONS

Unless all surfaces are thoroughly degreased and level, poor adhesion to the substrate can result. Typical preparation for light metals is sandblasting at 60-75 psi with 100-120 mesh alumina, flintshot or quartz. Steel and cast iron should be prepared with 50-100 mesh. Parts should not be handled after surface preparation. If a great deal of time has elapsed between surface preparation and application, the part should be heat cleaned at 700° F.

PRIMER COAT (if required)

Primer Liquituf* 2-376 is a water based PPS primer. Apply as follows:

1. Agitate Dispersion—Using a roll mill or slow agitation with stirrer. Do not agitate vigorously.
2. Cure at 750°F. for 30 minutes. Do not over cure if maximum intercoat adhesion is required. A second coat can be applied if desired. Use same spraying and baking instructions.
3. Apply PPS powder directly over primer. Powder topcoat can be applied either cold or hot. If going hot put thin powder coat over primer immediately after removing from 750°F. oven. This will help establish a good bond between primer and topcoat. Subsequent powder application can be made at 750°F.

ELECTROSTATIC APPLICATION

A. Suggested Voltage—30-70 kV
   Charge—negative (optional)

B. Thin Films (5-8 mils)
   Preheat part to 750-800°F. Surface Temperature should be 750°F. Spray the part hot until desired build is obtained. Single coats should not exceed 4 mils. Excessive build on initial coat can cause sagging or blistering. Return part to oven and cure part at 750°F. surface temperature for a minimum of 45-60 minutes. If higher gloss is required, part should be water quenched.

C. Multiple Coats
   Apply first coat as described for thin films. Return part to oven and cure for 30 minutes at 750°F. Remove part from oven, spray hot to desired build. (Do not exceed 10 mils per pass.) After each intermediate coat return part to oven for 45 minutes. After the final coat a full bake cycle of 60 minutes at 750°F completes the cure. Gloss can be improved by water quenching. (Note: TFE Lubricated Grades do not develop high gloss.)

FLUIDIZED BED APPLICATION

Bed should be thoroughly cleaned of other materials. PPS utilizes normal fluidization pressure (2-5 psi). Bulk density in fluid suspension is 30.3 pounds/ft^3.

Parts should be preheated to equilibrium at 750°F (surface temperature 750°F) and dipped in the fluidized powder 5-10 seconds. The maximum build for the first coat should be 12-15 mils. A full cure is achieved by returning the part to the oven and baking at 750°F for 60 minutes. If additional build is required a partial cure for 45 minutes should be completed prior to redipping the part. Subsequent build may be from 15-20 mils. After the final coat the part should be cured for the full cycle.

PATCHING

For surface that cannot be covered by rejigging and secondary powder applications, the following technique is recommended:

> Heat the exposed area with infrared or hot air gun, apply powder over the area and reheat until smooth coating is obtained. Avoid degradation of polymer and inhalation of fumes.

NOTE: It is important to remember that the patch area must receive the full cure (cross-linking). Patch area must be heated to a minimum temperature of 700°F. for 30 minutes.

For patching of metal, use LNP Filler F-1000.

STRIPPING

PPS can be most effectively removed by heat stripping at 1200°F. Bake-off time 2-3 hours. Scraping can also be facilitated by the use of a blow torch. This should always be done in a ventilated area.

TROUBLE SHOOTING

Blistering: This is usually caused by excessive powder build or by too short a cure between successive builds.

Cracking: The part has not been cured long enough. During early stages of the cure, part surface will be exceptionally smooth. If the part is removed at this point, cracks are sure to form. Check recommended cure conditions.

Sagging: This can be caused by two factors - 1) improper bake temperature will result in flow without cure, and 2) excessive build also contributes to sagging.

Pinholes: Moisture contamination is the principle cause of pinholes. Poor powder transfer and fluidization usually accompany this. If moisture is suspected dry the material at 250° F. for 3 hours.

Storage: Powders should be stored only in closed containers in a co ol, dry environment. Open containers increase the chance of contamination and introduction of moisture.

CAUTION—PTFE Lubricated Grades—Keep curing ovens well ventilated. PTFE gives off toxic fumes over 750° F. Stripping should be done in well ventilated area to prevent inhalation of fumes.

APPENDIX D

CONTACTS

COMPANY NAME & ADDRESS	CONTACT	POSITION/ PHONE NO.
Doble Engineering 25 Walnut St. Watertown, Mass. 02172	L. Melia D. J. Kopaczynski	 Asst. Mgr, Filed Service 617-926-4900
EI DuPont de Nemours Polymer Products Dept. Industrial Films Div. Wilmington, Delaware 19898	Francis W. Peri	Development & Technical Mgr. - Kapton 302-773-3216
	Stephen Simpson	Technical - Kapton 302-999-4810
	Robert A. Samoden	Kapton Group 302-774-6964
Polymer Products Dept. P.O. Box 89 Circleville, Ohio 43113	Arthur Neal Hamilton	Kapton Technical Service 614-474-0307
General Electric Company Power Transformer Dept. Building 11	Dr. W. A. Fessler	Mgr., Insulation Materials 413-494-4391
100 Woodlawn Avenue Pittsfield, Mass. 01201	T. Sherer	Senior Engineer 413-494-3182
Hysol Division The Dexter Corporation 211 Franklin Street Olean, New York 14760	Douglas Smith	Polymer Chemist 716-372-6300
R. P. Morrison Company 49 Madison Avenue Wickford, R.I. 02852	R. P. Morrison	Hysol Rep. 401-295-5692
Indiana Institute of Technology 1600 East Washington Boulevard Fort Wayne, Indiana 46803	R. B. Duke	Director of R&D 219-422-5561 (Make NEMA Test Instruments
LNP Corporation 412 King Street Malvern, Pa. 19355	Kurt McCadden	Fluorotechnologist 215-644-5200
	R. D. Rainone	Technical Sales Rep Fluoropolymer Products 215-644-5200/401-295-0172
3M Company Industrial Electrical Products Division 225-45 3M Center St. Paul, Minn. 55144	J. Tomita	Supervisor, Polymer Dev. 612-733-2385

Phillips Chemicals Co. 2600 North Loop West 3rd Floor Houston, Texas 77092	James Hubbard	Area Field Sales Supervisor Ryton (PPS) 800-231-3630
	Gregory Lane	Sales Engineer New England Area 800-231-3630

DOBLE ENGINEERING COMPANY
ELECTRICAL INSULATION TEST ENGINEERS AND CONSULTANTS
FIELD TESTING AND MAINTENANCE OF HIGH VOLTAGE INSULATION

July 19, 1983

Mr. Mack Wells
Magnetic Corporation of America
179 Bear Hill Road
Waltham, MA 02254

Dear Mr. Wells:

Re: Your Purchase Order No. 16304

In accordance with the subject purchase order, corona tests were made on 22 samples of generator wire on July 1, 1983. Enclosed is our report No. 1 covering the results of these tests.

We hope the information is helpful to you and we understand that we can look forward to being of further service in the near future.

Very truly yours,

S.H. Osborn, Jr.
Manager, Field Service

Enclosure
SHO:emr

85 Walnut Street Watertown, Massachusetts 02172 Tel. 617-926-4900 TWX 710-327-6338

Report No. 1
To
Magnetic Corporation of America
Corona Tests on Insulated Generator Wire

Corona tests were made on 22 samples of generator wire on July 1, 1983 in the Doble laboratory, Watertown, Massachusetts. The tests were made in accordance with Magnetic Corporation of America P.O. No. 16304 and were witnessed by Frank Parks and Joe Ferrante of the Magnetic Corporation of America.

The Corona Test setup was made according to ASTM D 1868, Detection and Measurement of Discharge (Corona) Pulses in Evaluation of Insulation Systems. The setup was according to Figure 4 of the method with a coupling capacitor of 100 picofarads, corona free up to 15kV and a calibrating capacitor of 142 picofarads. The coupling impedence, detector, and calibrating signal were part of the Biddle Balanced Partial Discharge Detector Catalog No. 665702. To aid in the detection of corona an oscilloscope was connected to the amplifier output. The oscilloscope was set for an output of 10 picocoulombs per division. The Biddle detector was set to two picocoulombs or above.

The wire samples were bent in a U shape form with approximately 4" resting on a 6" square ground electrode. The samples were held in place by two strips of tape 3" apart. The samples and ground electrode were immersed in oil. Sixty Hz, AC voltage was applied to the wire with the aluminum plate grounded. An adjustable AC high voltage supply was used which is corona free up to 12 kV. In addition a filter was used to remove line noises. High voltage was measured with a (130 to 1) ratio potential transformer with a Hewlett Packard 3400A RMS volt meter on the output.

The voltage was brought up slowly until steady corona (two to three picocoulombs) appeared on the oscilloscope. This voltage was recorded. The voltage was reduced until corona disappeared. This voltage was recorded. The voltage was brought up again until heavy corona above 3 picocoulombs or breakdown occurred. The breakdown voltage was recorded and the heavy onset corona voltage was recorded when applicable. A visual inspection of the specimen was made after the test to determine where breakdown occurred. A table of the test data is included along with some pictures of the test equipment.

Report prepared by:

L J Melia

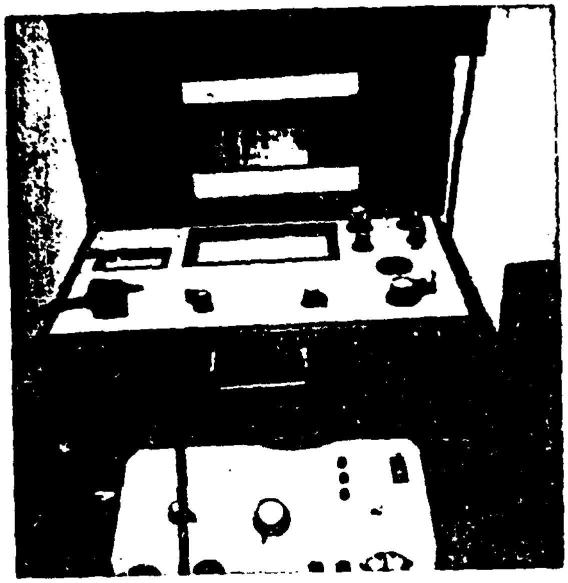
L. J. Melia

LJM:acl

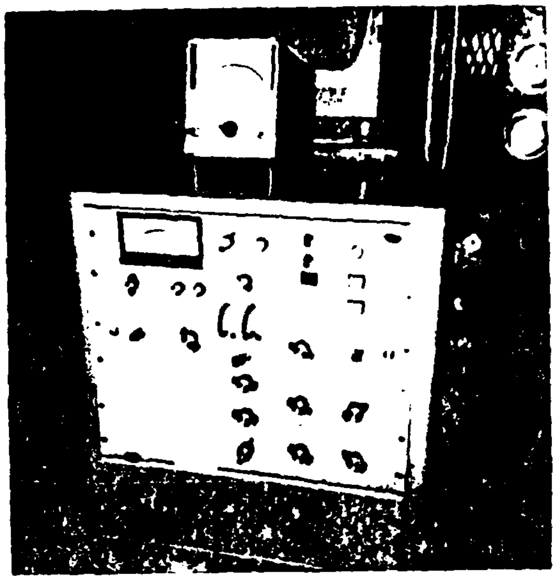
Item No.	Ident.	C.I.V.	C.E.V.	Corona V. Above 3pc.	Breakdown Voltage	Breakdown Point
1	3M	1430	1170	-	1430	Edge
2	3M	468	201	-	800	Edge
3	3M	1625	845	-	3510	Edge
4	3M	1690	1495	-	2211	Edge
5	Hysol	1625	1365	3900	3900	Edge
6	Hysol	3250	2106	4160	4160	Middle
7	Hysol	910	0	-	780	Edge
8	Hysol	1300	0	-	1300	Middle
9	Hysol	715	0	-	715	Middle
10	-	715	0	-	715	Middle
11	ETFE	3185	2600	7176	9360	Middle
12	ETFE	2730	1755	7800	8840	Middle
13	ETFE	2002	1625	-	6240	Middle
14	Polymer	780	0	-	780	Edge
15	PPS	2340	1690	8450	9750	Middle
16	PPS	2860	1300	-	7800	Bend
17	ETFE	1950	1170	3250	7150	Edge
18	Polymer	1950	1495	3120	5850	Middle
19	Tec Wire	1560	520	4602	4680	Middle
20	Tec Wire	3250	2210	4550	5070	Edge
21	Kapton	1950	1365	4940	5460	Edge
22	Kapton	2795	1495	5200	5720	Overlap

C.I.V. = Corona Initiate Voltage

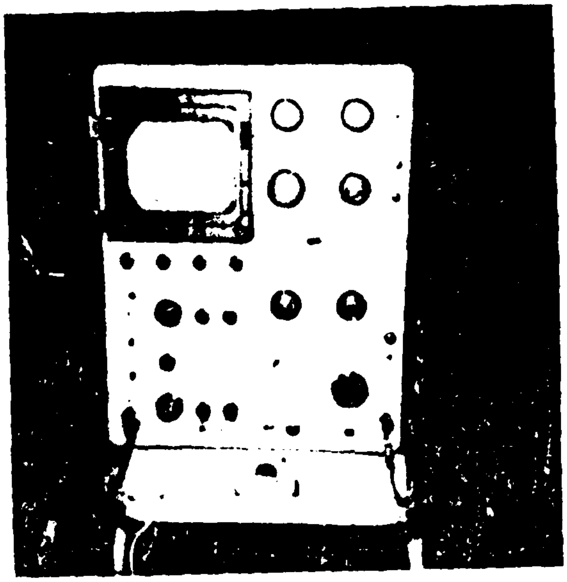
C.E.V. = Corona Extinction Voltage



Voltage Supply

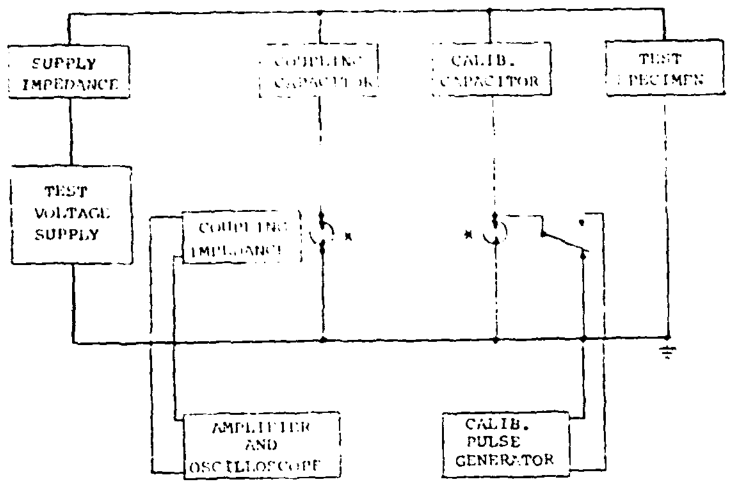


Corona Detector



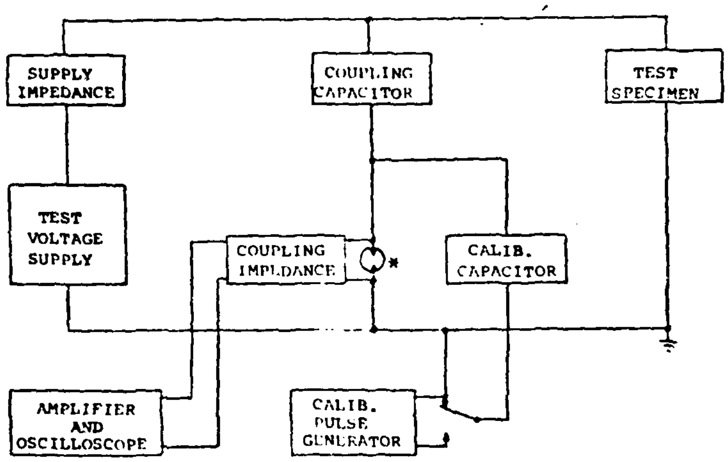
Oscilloscope

Coupling Capacitor + Test Tank



*Surge Protector (Optional)

FIG. 3 Circuit for Corona Measurement Including Calibration Equipment—Circuit No. 3.



*Surge Protector (Optional)

FIG. 4 Circuit for Corona Measurement Including Calibration Equipment—Circuit No. 4.

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